FISCAL YEAR 1989 DEPARTMENT OF ENERGY AUTHORIZATION

(Supporting Research and Technical Analysis, Energy R&D, and General Science and Research Programs)

HEARINGS

BEFORE THE

SUBCOMMITTEE ON
ENERGY RESEARCH AND DEVELOPMENT

OF THE

COMMITTEE ON
SCIENCE, SPACE, AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

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1989 DEPARTMENT OF ENERGY AUTHORIZATION

WEDNESDAY, MARCH 23, 1988

House of Representatives,
Committee on Science, Space, and Technology,
Subcommittee on Energy Research and Development,
Washington, DC.

The Subcommittee met, pursuant to notice, at 1 p.m., in room 2325, Rayburn House Office Building, Hon. Terry L. Bruce presiding.

Mr. Bruce. This Subcommittee will come to order. The Subcommittee will be reviewing the Department of Energy's fiscal year 1989 request for supporting research and technical analysis programs. Pressing obligations have prevented Chairman Lloyd from being here today, and she has asked me to pinch hit for her. I will try to do the best I can.

I know that I speak for the Chairman and all members of the Subcommittee when I say that this program, which contains the basic energy sciences program within the Department of Energy's Office of Energy Research, represents one of the most important national scientific efforts funded by the Federal Government.

Within this program, pioneering research in the area of high-temperature superconductivity is being conducted; new technologies and instruments of research and developed to analyze materials; chemical processes and other phenomena critical to our energy future. It is through these programs that scientists and engineers at our national laboratories and at our universities make discoveries which expand our knowledge and that lead to new technologies and new energy resources.

The Department's request for fiscal year 1989 for the supporting research and technical analysis program amounts to $610 million, of which more than 84 percent is used to fund the Basic Energy Sciences program. The request includes an increase of just $26 million over the appropriated levels, excluding Congressional construction initiatives for the Basic Energy Sciences program or BES.

Today, we will be examining whether or not this increase of roughly 5 percent can and will be adequate to meet the task before the Nation in Basic Energy Sciences research. At first glance, the Department is to be commended for providing this increase in this time of really extremely tight budgets.

However, closer examination suggests that the funding levels are not adequate to sustain such a dynamic and growth oriented program as BES. Projects that the Congress has deemed essential to enhancing our international competitiveness and to strengthening the research capabilities of our universities are included in this effort.

However, funding for these initiates as well as certain other programs aimed at assuring timely and cost-effective completion of major new user facilities for scientific research has been excluded or substantially reduced.

The eight witnesses that will testify today before the Subcommittee should provide us with a comprehensive view of just what the program has to offer in its present form, as well as discussing the shortcomings which I have already mentioned. Hopefully through such discussions as we will have here today, the Subcommittee will be provided the information needed to make any corrective actions that are required.

At this time, I recognize the distinguished Ranking Republican Member of the Subcommittee, Congressman Sid Morrison from Washington State for his opening remarks.

Mr. **Morrison**. Thank you very much, Mr. Chairman and good afternoon. Today the Subcommittee will review in detail activities covered within DOE's Basic Energy Sciences programs. These programs serve as an important link among universities, National Laboratories and industry. There are 1,400 projects in the major scientific user facilities supported by these programs that provide this nation with many breakthroughs in physical, biological and mathematical sciences and created many award winners in these areas.

The return of our investment in BES programs is certainly well worth the investment. I am pleased with the impressive accomplishments in high-temperature superconductivity and related research last year, and also want to add my congratulations to our Nobel Prize Winner, Professor Donald Cram from UCLA for his outstanding contribution to the chemical sciences.

I am delighted that the DOE continues to support funding for these Basic Energy Sciences projects that foster innovative ideas. A new item proposed by the DOE this year is the Basic Research User Facility account for the BES. Included under this appropriation would be funding for construction, operation and maintenance of the major user facilities related to basic energy-related research.

I think separating the facility support for research projects is a dandy idea because we can keep better track of the accounting system and the researchers would probably be more productive when they don't have to worry about funding cuts in their projects and appear before this Subcommittee each year. Of course, there are quite a few issues about facilities yet to be resolved, but this is a positive first step in resolving those issues.

Finally Mr. Chairman, I would like to mention a new initiative by the Pacific Northwest Laboratory to construct and operate a Molecular Science Research Center. This is a national facility which would provide leading edge equipment to a diverse group of researchers in various disciplines from National Laboratories, universities and industry.

I believe it is a wise investment that could achieve many happy returns. I am excited about this program, and I am glad that the

Subcommittee will hear details on this program from Dr. Bill Wiley, who is with us this afternoon.

Thank you, Mr. Chairman, for the opportunity to make this statement.

Mr. **Bruce**. Thank you, Mr. Morrison. Mr. Fawell, do you have an opening statement?

Mr. **Fawell**. No, I do not, Mr. Chairman. Thank you.

Mr. **Bruce**. All right. With that, we will start with our witnesses. We are happy to have with us, Dr. James Decker, Acting Director of the Office of Energy Research, Department of Energy.

He will be followed by Dr. Robert Sproull, Chairman of the Basic Energy Sciences Advisory Committee and two panels composed of members of the Oak Ridge National Laboratory; Argonne; Pacific Northwest Laboratory; Brookhaven National Laboratory; Sandia National Laboratories; and Stanford Synchrotron Radiation Laboratory.

Dr. Decker, we are happy to have you with us this afternoon, and look forward to your testimony.

STATEMENT OF DR. JAMES F. DECKER, ACTING DIRECTOR, OFFICE OF ENERGY RESEARCH, U.S. DEPARTMENT OF ENERGY, WASHINGTON, DC; ACCOMPANIED BY DR. DONALD K. STEVENS, ASSOCIATE DIRECTOR, OFFICE OF BASIC ENERGY SCIENCES, AND DR. RICHARD E. STEPHENS, DIRECTOR OF UNIVERSITY AND INDUSTRY PROGRAMS

Dr. **Decker**. Thank you, Mr. Chairman and Members of the Committee. I am pleased to have this opportunity to speak to you today about the Department's fiscal year 1989 budget request for Basic Energy Sciences, Energy Research Analysis, University Research Support, University Research Instrumentation, and Multi-Program Energy Laboratory Facilities Support. Accompanying me today are Dr. Donald K. Stevens, who is the Associate Director for Basic Energy Sciences and Dr. Richard E. Stephens, who is the Director of the Division of University and Industry Programs.

First, I want to talk about the Basic Energy Sciences Program. This program supports long-range scientific research aimed at improvements in the efficiency, reliability and economy of our country's energy systems. Research results from this program contribute to the broader development of applied technologies.

The Program supports about 1,200 separate research projects at over 200 institutions. The effort includes research in the physical, biological, and mathematical sciences. Basic Energy Sciences supported research also trains future scientists and engineers through the participation of students on research projects at universities and the National Laboratories.

The national contribution of the BES program to the country's science infrastructure is that it provides unique user facilities for university and industrial researchers, as well as scientists from our National Laboratories. Examples of these facilities include synchrotron light sources, atomic resolution microscopes, research reactors and so forth.

In the fiscal year 1989 budget request, we provide funds to continue our research programs and support for operating our user facilities. In fiscal year 1989 we are requesting the first construction funds, $6 million, for the 6/7 GeV Synchrotron Light Source to be built at the Argonne National Laboratory.

This facility will provide the scientific and industrial community with a third-generation synchrotron radiation source in the hard x-ray region. This new, intense source will enable scientists to observe new phenomena and allow measurements of a more precise nature in many fields, including materials science, chemistry, biology and medicine.

This facility has been given the highest priority by several prestigious studies of new facilities required for materials research.

Next, I would like to turn to some of the accomplishments of this program in the last couple of years.

Several accomplishments of the program have recently been recognized by prestigious awards; the 1987 Nobel Prize in Chemistry, as was mentioned by Mr. Morrison, was shared by Donald Cram of UCLA for his work under the sponsorship of this program.

This developed new, energy-efficient chemical methods for recovering scarce metals and for purifying waste streams of toxic or radioactive wastes. The IR–100 Award was received by Dr. Suckewer of Princeton, for the development of the first x-ray laser. When fully developed, the x-ray laser may lead to microscopes that can look inside living cells.

This program also sponsored research that has been in the forefront of high-temperature superconducting materials. This research area provides an excellent example of the interplay between researchers and our general-purpose user facilities.

Reactors and pulse neutron sources have been used for neutron scattering studies to provide information about the atomic structure of these new materials. Synchrotron light sources have been used to study properties of electrons in high-temperature superconductors. Supercomputers have been used by theorists to model the properties of these materials and search for explanations for their superconductivity.

We expect that this research will lead an understanding of why these materials are superconducting and to the ability to develop and improve materials with better electrical and mechanical properties for applications. As part of the present superconductivity initiative, three centers were established at the Lawrence Berkeley Laboratory, the Ames Laboratory, and the Argonne National Laboratory, to focus our superconductivity research efforts and to provide information to universities and industry.

These centers are also contributing to the computer database that was established by the Departments Conservation Program at Oak Ridge. In addition, the Department has asked the Los Alamos National Laboratory to look into innovative ways to accelerate the transfer of this new technology to industry.

Next, I wanted to briefly describe some of our activities in university research support. Over the last few years, the Department, under Secretary Herrington's leadership, has undertaken a number of initiatives to make its laboratories more available to students and teachers, or scientific research and education activities.

These initiatives may be summarized as follows. First, we have a high school student honors program, where we get the best and brightest students from each State to participate in research at DOE laboratories. In this fiscal year we have added a new program at the Oak Ridge National Laboratory in Environmental Science. In fiscal year 1989 we will be adding another program at the Pacific Northwest Laboratory in Ecology.

Laboratory science education centers establish year-round faculty for student teacher programs. We have that going at five laboratories. Initial emphasis is on semester research programs for undergraduate students. In fiscal year 1989, the request expands support for science education centers and also adds the Los Alamos National Laboratory to the list of centers.

We have a new initiative for high school science teachers in fiscal year 1989. It will bring 200 high school science teachers to DOE laboratories for summer research. We are working very closely with the National Science Foundation on this and other pre-college science education activities.

Our science education programs extend over all levels of education: pre-college, student and teacher programs at labs, undergraduate programs, and post-doctoral programs as well. In fiscal year 1989, the request will support the following numbers: 1,500 undergraduates; 550 high school science students; 200 high school science teachers; 300 graduate students; and 200 faculty, all spending part of the year carrying out research or science education projects at the DOE laboratories. All of these programs are national in scale.

These efforts are important because they are aimed at tempering the projected shortfall of scientists and engineers in the 1990's. The general principle is to bring students or teachers to the laboratory where they can work one on one with scientists and engineers. This one on one approach seems to be very effective, not only to impart information but to show by personal example, the attractiveness of science careers.

Follow-up studies on these students have shown that students who participate in these projects are much more likely to continue careers in science. I think these programs illustrate how the unique resources of the Department's National Laboratories can be used in many ways to meet the needs of the country.

I thank you very much, and I would be pleased to answer any questions that you may have.

[The prepared statement of Dr. Decker follows:]

Statement of James F. Decker

Acting Director

Office of Energy Research

Department of Energy

before the

Subcommittee on Energy Research and Development

of the

House Science, Space and Technology Committee

March 23, 1988

Madam Chairman and Members of the Subcommittee:

Scientific and technological advances in medicine, the physical and mathematical sciences, and biology have contributed to better health and an improved quality of life for each of us and to economic health, national security and energy self-sufficiency for the Nation. The Office of Energy Research (ER) programs are an essential component of the scientific base that has made it possible to achieve these goals. To remain competitive and ensure our future, we must continue our commitment to the scientific research that continually replenishes that base of knowledge on which the technologies rest.

The ER programs that I will discuss today make a major contribution to that base and to achieving our national goals. The total FY 1989 budget request for all ER programs is $2.4 billion (Table 1). The FY 1989 budget request for the programs that I will discuss today is $610.6 million which can be compared to $647.3 million in FY 1988. These programs include: Basic Energy Sciences (BES), Energy Research Analysis (ERA), University Research Support (URS), University Research Instrumentation (URI), Multiprogram Energy Laboratories-Facilities Support (MEL-FS), and supporting program direction. The FY 1989 request for BES falls under two appropriations: Energy Supply R&D and the new Basic Research User Facilities appropriation which I will discuss later in my statement. All of the other programs I will discuss today are under Energy Supply R&D.

Table 1
Office of Energy Research
Summary by Program
Budget Authority
($ in millions)

	FY 1987	FY 1988	FY 1989 Request
Energy Supply R&D			
Basic Energy Sciences	$432.3	$437.2	$375.6
Magnetic Fusion Energy	341.6	335.0	360.0
Biological & Environmental Research	191.1	269.3	249.0
University Research Support	15.6	18.4	15.8
University Research Instrumentation	4.9	5.0	5.0
Energy Research Analysis	2.0	3.7	3.8
Advisory & Oversight Program Direction	2.5	3.2	3.3
Policy and Management	0.6	0.7	0.7
Multiprogram Energy Laboratories-Facilities Support	56.7	53.6	65.9
Subtotal	$1,047.3	$1,126.1	$1,079.1
General Science & Research			
High Energy Physics	$201.9	$217.4	$220.4
Nuclear Physics	122.2	134.9	141.4
General Science Program Direction	2.5	2.8	3.2
Subtotal	$326.6	$355.1	$365.0
Basic Research User Facilities			
Basic Energy Sciences	$ 87.2	$125.5	$140.5
Nuclear Physics	92.7	110.2	122.7
High Energy Physics	273.4	314.2	346.4
Superconducting Super Collider	20.0	25.0	363.0
Subtotal	$473.3	$574.9	$972.6
Total ER	$1,847.2	$2,056.1	$2,416.7

BASIC ENERGY SCIENCES

Basic research is the first link in the chain of events from scientific discovery to economic growth through technological innovation. Results from research sponsored by the Basic Energy Sciences (BES) program become an integral part of the information base used in the development of the applied technologies within the Department and are equally important within the private sector. In addition to underpinning technology development, BES-supported research activities train our future scientists and help us attain our national goals--better health and quality of life, economic strength, energy self-sufficiency, national security--goals calling for continuing and significant technological advances.

The BES program annually supports approximately 1400 research projects at over 200 separate institutions with direct support for about 4000 investigators in the physical, biological, and mathematical sciences. These projects are selected on the basis of scientific excellence, relevance to DOE long-term goals, and their contribution toward a program responsive to the needs of the Nation. BES also provides funding for the supercomputer centers used for computation by the High Energy Physics, Nuclear Physics, and Biological and Environmental Research programs as well as for its own program.

The Basic Energy Sciences program undertakes research primarily at national laboratories and universities and, to a lesser extent, at private research laboratories and other government laboratories. The majority of BES-supported research is carried out at national laboratories. These laboratories are especially valuable in conducting basic research because researchers there also are involved in many aspects of the applied energy programs, thus facilitating transfer of scientific information and technology from experiment to application. In addition, the stability of the organization and specialized capabilities which exist at the laboratories in many instances are unmatched. The BES program also provides significant support to universities both directly and through the participation of university faculty members, postdoctoral students or graduate students in research at the national laboratories and at user facilities.

In addition to universities and national laboratories, BES supports research in and maintains strong ties with industry. Representatives from different industries serve on the BES Advisory Committee; experts from industry participate in the review of research proposals and use the specialized facilities sponsored by BES; industrial scientists participate in advisory committees to the national laboratories; and industry representatives are invited to attend BES conferences and workshops on special topics.

No summary of research results for such a diverse program can ever be complete or even fully representative of the program. Since the BES program covers such a wide spectrum of research, I can highlight only a few accomplishments in this statement. I would be happy to supply the Committee with additional representative accomplishments for each of our research areas.

Of special note, a BES project at UCLA has been recognized by a share of the 1987 Nobel Prize in Chemistry. The Prize was awarded to Professor Donald J. Cram of UCLA, Dr. Charles J. Pedersen of DuPont and Professor Jean-Marie Lehn of the Louis Pasteur University for developing new chemical methods for recovering scarce metals and purifying common metals using much less energy than in the past. Professor Cram's research program is providing new insight into the selective binding of materials which can "tie up" a valuable metal in the presence of other common ones and allow the new chemical combination to be extracted. The novel substances prepared by Cram's research team can bind molecules as well as metals and can be designed to mimic the highly specific activity of enzymes, the remarkable catalysts that are essential to all forms of life. Thus, in addition to the applicability of Cram's work to recovery of scarce metals and purification of waste streams of toxic or radioactive metals, the principles he has discovered also have widespread implications for the understanding of many processes that occur in nature.

In the materials sciences area, theoretical modeling of materials phenomena provides a basis for predicting the behavior of materials and can be very valuable in supporting experimental results and uncovering new phenomena. Recent application of a newly developed theoretical technique has resulted in the calculation of stress levels that cause brittle cracks to grow in materials. This knowledge will help us to determine safe stress levels without the time consuming process of testing every possible composition and structure.

An important "first," the demonstration of the x-ray laser, received one of the 1987 IR-100 awards which are presented annually by Research & Development magazine to the 100 most significant new technical products in the world. When fully developed for microscopy purposes, laser-based x-ray microscopy offers, for the first time, the prospect of observing the insides of living cells, including the distribution of chemical elements within a cell. The first microscopic images using the x-ray laser were recently obtained but the wavelength of the laser is still too long to image the cells; further work is in progress.

Last year was also an important year in the development of high-temperature superconductors. Although superconductivity was discovered in 1911, applications to date have depended on cooling with liquid helium. At the end of 1986, a breakthrough occurred in the temperature limit and newly developed "high-temperature" materials have now been found which superconduct above the temperature of liquid nitrogen which is considerably cheaper and easier to use than liquid helium. To take advantage of the discovery of the new class of high-temperature superconductors, the Office of Basic Energy Sciences has supported research aimed at addressing scientific and technical obstacles that must be overcome to use the new materials in technologically important systems. The BES research program is addressing fundamental questions regarding the mechanism by which the new high-temperature superconductor materials become superconducting, the key to finding even better new materials. The program also is addressing the synthesis of new materials to expand the range of these parameters.

The national laboratory structure and the availability of BES's major user facilities have been critically important to the ability of the BES program to quickly redirect research into this important area. Although the funding request for these facilities is now under the Basic Research User Facilities appropriation which is discussed later in my statement, I would like to discuss some of the contributions being made by BES research to our ever-growing understanding of high-temperature superconductors.

Within a few weeks after the discovery of the new higher temperature superconductors, scientists at Argonne National Laboratory's Intense Pulsed Neutron Source carried out neutron scattering studies of the yttrium-barium-copper oxide material and produced definitive results on its structure. This new information on the exact arrangement of the atoms in the compound has provided the basis for understanding all of the subsequent experiments conducted and theories developed to understand why these compounds are superconducting at such high temperatures.

At the High Flux Beam Reactor (HFBR), scientists are learning more about two phenomena that play a key role in high-temperature superconducting materials, atomic vibrations and the properties of electrons within these materials. Neutron scattering studies of atomic vibrations have confirmed scientists' belief that the behavior of these materials is similar to conventional low-temperature superconducting materials. However, other neutron scattering research at HFBR led to unexpected behavior related to electron properties giving rise to magnetism. Specifically, in the pure lanthanum-copper oxide material, the copper oxide sheets exhibit a novel type of magnetic order at quite high temperatures. Thus, from the neutron scattering results, one normal and one unanticipated, a number of questions still remain that have to be explored further.

Synchrotron radiation also is useful to study electron properties in materials. By illuminating the superconductors with light from Brookhaven's National Synchrotron Light Source (NSLS), it was possible to excite the electrons from the different atoms and determine their energies or velocities within the material. Studies of the yttrium-barium-copper oxide superconductor showed that the electrons do not have energies as high as the calculations would suggest and that only a small number of electrons have the highest energy. This latter observation is contrary to what had normally been anticipated for superconductors. This work was one of the first reported photoemission studies of the high-temperature superconductors and the unusual results have now been confirmed by other groups.

FY 1989 BASIC ENERGY SCIENCES BUDGET REQUEST

The FY 1989 budget request for the research portion of the BES program is $375.6 million. Of the total, $344.4 million is for Operating Expenses; $25.6 million is for Capital Equipment; and $5.6 million is for Construction (Tables 2 & 3). The overall increase in funding for the Basic Energy Sciences program is 3 percent if FY 1988 Congressionally initiated projects are excluded. This request falls under the Energy Supply R&D appropriation. I will discuss the Basic Research User Facilities request for BES separately.

Table 2
Energy Supply R&D
Basic Energy Sciences
Budget Authority
($ in millions)

	FY 1987	FY 1988	FY 1989 Request
Operating Expenses			
Materials Sciences	$118.6	$126.0	$134.6
Chemical Sciences	79.2	88.2	93.1
Applied Mathematical Sciences	38.3	42.4	43.0
Engineering and Geosciences	29.1	31.4	33.4
Advanced Energy Projects	12.6	14.3	14.6
Energy Biosciences	16.3	20.2	20.8
Program Direction	4.1	4.5	4.9
Subtotal	$298.2	$327.0	$344.4
Capital Equipment	24.6	25.0	25.6
Construction	109.4	85.1	5.6
Total Basic Energy Sciences	$432.2	$437.2	$375.6

Table 3
Energy Supply Research and Development
Basic Energy Sciences
Budget Authority
($ in millions)

Construction

Project	TEC	FY 1988	FY 1989
Accelerator Improvement Projects (89-R-401)	$ 0.7	-	$ 0.7
General Plant Projects (89-R-400)	4.9	-	4.9
General Plant Projects (88-R-400)	4.9	$ 4.9	-
Center for Advanced Materials (84-ER-112)	40.2	7.6	-
Congressionally Initiated University Projects		72.6	-
		$85.1	$ 5.6

The Operating Expenses request will allow us to conduct research aimed at uncovering new energy-related information in materials sciences, chemical sciences, applied mathematical sciences, engineering and geosciences, energy biosciences and advanced energy projects. Specifically, the FY 1989 budget will provide the necessary resources to maintain the existing core program in each of the subprograms in BES and to permit initiation of a limited number of new research projects in those areas that have the highest scientific merit.

No two areas of scientific research illustrate better the stakes, promises, and consequences of research funding better than semiconductors and superconductors, which are funded in our Materials Sciences subprogram. Each holds out the hope of new technological advances. Future developments in computers, transportation, energy, defense, and medicine will be affected by the speed at which advances take place in these technologies.

The discoveries and advances in these areas have the entire scientific community excited. In high-temperature superconductivity, the Operating Expenses request will continue to fund research on methods for preparing superconducting materials with better properties, such as higher critical currents. Newer materials are also being investigated to understand the structure and mechanism of high-temperature superconductivity. The FY 1989 request includes $16.7 million, an increase of $1.5 million, for high-temperature superconducting research in the BES program.

The Department has played an important role in the development of the U.S. semiconductor technology base and continues to support research in this area. Semiconductors are materials that form the base for all solid state microelectronics circuitry. In FY 1989, semiconductor research supported by the Basic Energy Sciences program will continue to emphasize the science related to compound semiconductors and to provide synchrotron radiation useful to the Nation's researchers in studies of semiconductors. The FY 1989 level of funding in research related to semiconductors is planned to be about the same as in FY 1988, approximately $7.0 million.

Continued support will also be provided in FY 1989 for basic combustion research which will be important for providing advances in coal technology, engines, and for handling the spectrum of environmental problems in any combustion system. The level of funding in FY 1989 will be $15.1 million, an increase of $0.3 million. Scientists are uncovering new knowledge about the chemistry and kinetics of combustion that ultimately will enable automobile companies and utilities to improve operating systems.

The FY 1989 request for Program Direction is $4.9 million. These funds are required to pay for the personnel costs of 63 full-time equivalents to direct, manage, and support BES's multidisciplinary research efforts.

The Capital Equipment request for FY 1989 is $25.6 million. These funds will ensure that BES-supported researchers will continue to have the equipment needed to conduct advanced research, much of which involves experiments at extremes of temperature and pressure. Reliable, precise measurements under these conditions challenge the current state-of-the-art. Replacements and new equipment funded under this request, which are important to the continued success of the program, include such items as electron microscopes, neutron spectrometers, molecular beam equipment and computers for equipment control and data analysis.

The Construction request for FY 1989 is $5.6 million. This request includes continued funding for General Plant Projects and Accelerator Improvement Projects. Each of these categories is comprised of several smaller projects which are necessary to maintain plant and facilities at several DOE laboratories. The projects include a wide spectrum of improvements from roads and buildings to safety and security upgrades necessary to protect property and personnel and to modify existing scientific facilities to allow the most cost-effective utilization of their technical capabilities.

BASIC RESEARCH USER FACILITIES - BASIC ENERGY SCIENCES (BRUF-BES)

The remaining part of the Basic Energy Sciences program which I would like to discuss falls under the Basic Research User Facilities (BRUF) appropriation. This new appropriation includes funding for construction, operation, and maintenance of the Office of Energy Research's major "user facilities." Construction and operation of these large, complex, and expensive facilities requires sustained, central federal support since they are far too large and costly to expect non-federal research institutions to provide such facilities for the benefit of the scientific community. These facilities provide a unique national resource for forefront research in areas related to the use and production of energy. Their continued operation is essential to ensure a continuous support of new knowledge, trained personnel and new directions for the energy well-being of the U.S. and to support the technology base that is vital to the Nation's economic future. It is important to note that the BRUF funds, which include operating expenses, capital equipment and construction, provide only for the construction, operation and maintenance of the facilities. The BES research conducted in these facilities continues to be funded under the Energy Supply R&D appropriation.

Within the Basic Energy Sciences program, seven existing major user facilities are included in this new appropriation together with R&D, capital equipment and construction funding for two new facilities under construction. The seven existing facilities are: the High Flux Beam Reactor and National Synchrotron Light Source at Brookhaven National Laboratory, the Combustion Research Facility at Sandia-Livermore, the Stanford Synchrotron Radiation Laboratory (SSRL) at Stanford University, the Intense Pulsed Neutron Source at Argonne National Laboratory, the Los Alamos Neutron Scattering Center at Los Alamos National Laboratory, and the High Flux Isotope Reactor (HFIR) and the Transuranium Processing Plant at Oak Ridge National Laboratory. HFIR is currently being refurbished, and we expect it to restart later this year. One of the new facilities, the 1-2 GeV Synchrotron Radiation Source at Lawrence Berkeley Laboratory is already under construction, and funding is being requested to initiate construction of a second new facility, the 6-7 GeV Synchrotron Radiation Source at Argonne National Laboratory. Each of these seven facilities is unique in the capabilities which it offers the scientific and engineering community; and the success and promise of these facilities in meeting the Nation's research needs has been praised by many high-level committees.

Earlier, I mentioned some of the many accomplishments, primarily in the area of superconductivity, made possible by the existence of these facilities which are the key to research progress in many fields, including the physical, biological and mathematical sciences. Their availability to a wide range of researchers from academia, industry, and other government laboratories makes them especially valuable to the Nation. To gain a better understanding of their scientific and, ultimately, economic importance one only has to look at the community of users involved in research at the National Synchrotron Light Source (NSLS). Table 4 shows some of the many university, industry and government organizations that take advantage of the research capabilities at NSLS.

In addition to allowing many non-DOE researchers to carry out research directly at these facilities, some of these facilities produce research materials that are made available to other organizations. For example, the High Flux Isotope Reactor (HFIR) and Transuranium Processing Plant at ORNL have produced two isotopes used in cancer therapy research supported by the National Cancer Institute. Einsteinium-253 and fermium-255, which emit alpha particles with short half lives, are bound to monoclonal antibodies which are able to direct these radionuclides and cytotoxic drugs to malignant sites. Alpha emitters are ideal for cancer therapy because their entire radiation energy is confined to a very small range. Therefore, the number of alpha

Table 4
Basic Energy Sciences
Basic Research User Facilities
National Synchrotron Light Source
(Sample of Users)

Universities

University of California
Georgia Institute of Technology
Georgia State University
Harvard University
University of Illinois
Louisiana State University
Massachusetts Institute of Technology
Michigan State University
University of New Orleans
University of North Carolina
Northwestern University
University of Oregon
University of Pennsylvania
Princeton University
University of South Carolina
Stanford University
University of Texas

Industry

AT&T
Exxon
IBM
Mobil
Celanese
Allied Signal
Union Carbide
3M
Boeing
Chevron
Smith, Klein and French
SRI
Xerox

Government

National Bureau of Standards
National Institutes of Health
Naval Research Laboratory
Veterans Administration
Lawrence Livermore National Laboratory
Los Alamos National Laboratory
Sandia National Laboratories

"strikes" required to kill a cancer cell is much smaller than for other types of radiation. It is also important that alpha emitters to be used in cancer therapy have relatively short half-lives so that the radiation dose to the patient can be better controlled.

The FY 1989 budget request for BRUF-BES is $140.5 million. Of that total, $86.3 million is for Operating Expenses; $6.1 million is for Capital Equipment; and $48.1 million is for Construction (Tables 5 & 6).

The BRUF-BES Operating Expenses request of $86.3 million provides for continuing the operation of the seven existing facilities funded in this account, including HFIR which, as I already indicated, is in a stand down condition but being readied for restart. Within the Operating Expenses request, $8.2 million is necessary to continue R&D activities associated with the 1-2 GeV Synchrotron Radiation Source at LBL and the 6-7 GeV Synchrotron Radiation Source at ANL. The R&D funds for the former are focused on improvements to the magnet lattice and related activities. For the 6-7 GeV Source, research activities will focus on prototypes of the dipole magnets and insertion devices.

Reliable, precise measurements at the seven BES facilities challenge the current state-of-the-art; and improvements and replacement hardware are necessary in a timely fashion. The Capital Equipment request of $6.1 million provides for high priority synchrotron radiation equipment and neutron scattering equipment.

Table 5
Basic Research User Facilities (BRUF)
Basic Energy Sciences
Budget Authority
($ in millions)

	FY 1987	FY 1988	FY 1989 Request
Operating Expenses			
National Synchrotron Light Source	$ 18.5	$ 19.6	$ 20.3
High Flux Beam Reactor	10.0	10.9	11.5
High Flux Isotope Reactor/ Transuranium Processing Plant	15.8	22.7	23.7
Intense Pulsed Neutron Source	5.0	5.0	5.4
Stanford Synchrotron Radiation Laboratory	9.8	10.3	10.5
Los Alamos Neutron Scattering Center	1.3	3.0	3.1
Combustion Research Facility	3.5	3.5	3.6
6-7 GeV Synchrotron Radiation Source	2.0	10.0	6.2
1-2 GeV Synchrotron Radiation Source	1.5	2.0	2.0
Subtotal	$ 67.4	$ 87.0	$ 86.3
Capital Equipment	6.5	6.7	6.1
Construction	13.3	31.8	48.1
Total BRUF-BES	$ 87.2	$ 125.5	$140.5

Table 6
Basic Research User Facilities
Basic Energy Sciences
Budget Authority
($ in millions)

Construction

Project	TEC	Prior Year	FY 1988	FY 1989
6-7 GeV Synchrotron Radiation Source (89-R-601)	$456.0	$ -	$ -	$ 6.0
Accelerator Improvement Projects (89-R-600)	1.6	-	-	1.6
Accelerator Improvement Projects (88-R-600)	2.3	-	2.3	-
3 GeV Spear Injector (88-R-403)	14.0	-	3.0	6.5
1-2 GeV Synchrotron Radiation Source (87-R-406)	98.7	1.5	18.0	30.0
Neutron Scattering Experimental Hall (87-R-403)	17.5	5.0	8.5	4.0
Total Construction		6.5	31.8	48.1

Of the $48.1 million BRUF-BES Construction request, $30.0 million is for the 1-2 GeV Synchrotron Radiation Source. The unique capabilities at this new facility will allow investigators from industry, universities and national laboratories to carry out new studies in many fields, including materials science, atomic and molecular physics, chemistry and biology. The FY 1989 request will permit continued construction and procurement activity leading to completion of the facility in 1992.

The Construction request also includes $6.0 million to initiate construction of the 6-7 GeV Synchrotron Radiation Source. This new facility would not only provide an advanced scientific capability unmatched in the United States, it also would provide much needed additional capacity in the hard x-ray region. As a third generation radiation synchrotron source, it will be used by many scientific disciplines to investigate new materials, surfaces, biological molecules, chemical reactions and geological materials. For these studies, the unprecedented quality of the x-ray radiation, including the intensity, coherence and time structure, will certainly provide the U.S. with important new discoveries. The need for this facility has been agreed upon by several organizations, including the National Academy of Sciences and the Department's Energy Research Advisory Board. This facility has received the highest priority recommendations from these groups.

The BRUF-BES Construction request also includes $6.5 million to continue construction of the 3 GeV SPEAR Injector so that synchrotron radiation experiments at Stanford Synchrotron Radiation Laboratory can proceed independently instead of relying on the availability of the SLAC linear accelerator which also injects into the Positron-Electron Storage Ring and the Stanford Linear Collider; $4.0 million to continue construction of the Neutron Scattering Experimental Hall at the Los Alamos Neutron Scattering Center; and $1.6 million for accelerator improvement projects at the National Synchrotron Light Source and the High Flux Beam Reactor.

At this point, I would like to discuss the several ER programs that are related to my statutory responsibilities to advise the Secretary on DOE's R&D programs, on the non-weapons multiprogram laboratories and on the education and training of scientists and engineers.

ENERGY RESEARCH ANALYSIS

The Energy Research Analysis (ERA) program performs technical assessments and research analyses that cut across all aspects of the Department's civilian R&D programs. These assessments and analyses provide technical support to the Director in carrying out legislatively assigned R&D oversight responsibilities. The ERA program focuses in depth on particular project or program areas and offers an independent view of how well research is conducted and where the most promising opportunities for future research lie. The program also plays a key role in coordinating the Department's involvement in acid rain research. Specifically, the program provides DOE'S share of the financial support for management of the National Acid Precipitation Assessment Program (NAPAP). In addition to providing funds, this program represents DOE on technical task groups and reviews documents produced by NAPAP and non-Federal groups for their scientific quality and objectivity.

The FY 1989 budget request of $3.8 million will provide continued funding for assessments of ongoing research on membrane separations technology, laser instrumentation and analytical chemistry of air pollution. In addition, analyses critical to the successful completion of the final National Acid Precipitation Assessment Program in 1990 will be conducted.

UNIVERSITY RESEARCH SUPPORT

The Department encourages universities and colleges to contribute to the national energy R&D effort, for these universities produce much of the new scientific knowledge and technical talent that ultimately enters the marketplace and contributes to the Nation's continued economic and social progress. University scientists and students conduct research sponsored by DOE in all areas of fundamental science and energy R&D. This support includes both direct awards for on-campus research and collaborative efforts involving DOE laboratory scientists and facilities. The Department also supports the involvement of faculty and students in two specific research and science education-related programs, the University Research Support (URS) Program and the related University Research Instrumentation Program, which I will discuss next.

The major objectives of the URS program are to: (1) strengthen university capabilities to perform long-range R&D; (2) enhance the quality and increase the numbers of young people pursuing energy-related R&D careers; (3) use the unique resources of the Department's laboratories both for university faculty and student research and training; and (4) enhance technology transfer to the private sector, thus assisting in the national effort to revitalize the Nation's economic position in the world marketplace.

The URS program, with an FY 1989 budget request of $15.8 million, consists of four activities: Laboratory Cooperative Science Centers, R&D Laboratory Technology Transfer, University Reactor Fuel Assistance, and Energy Manpower Development (Table 7).

The largest of the URS programs, with a request of $9.5 million, is the Laboratory Cooperative Science Centers. The essential roles played by the Department's laboratories in assisting university research and manpower development have been underscored in recent Energy Research Advisory Board and White House Science Council reports on the health of U.S. colleges, universities and industry. Consistent with these analyses and the President's goal of improving our national science and technology research and education base, an initiative was begun in FY 1988 to broaden and strengthen the Laboratory Cooperative Science Centers. This Program provides support for over 2100 summer research/instructional appointments at the DOE laboratories for university faculty and students. In addition, a new semester-length research program was initiated at five DOE multiprogram laboratories. Three hundred undergraduate science and engineering students were selected in a national competition. In FY 1989, support will be expanded to provide for 450 undergraduate science and engineering students and 36 faculty/student research

Table 7
Energy Supply R&D
University Research Support
Budget Authority
($ in millions)

	FY 1987	FY 1988	FY 1989 Request
Operating Expenses			
Laboratory Cooperative Science Centers	$ 9.9	$13.8	$ 9.5
R&D Laboratory Technology Transfer	0.8	1.0	1.4
University Reactor Fuel Assistance	3.8	1.9	2.1
Energy Manpower Development			
Energy Manpower Assessment	0.5	0.5	0.6
Energy Education and Training	0.6	1.2	2.2
Total URS	$15.6	$18.4	$15.8

teams to participate in the program at six labs. This expanded effort provides a year round focus for students and faculty research and education efforts.

In FY 1989 the R&D Laboratory Technology Transfer activity will provide joint support to 30 industry scientists and engineers to work on research assignments at national laboratories side-by-side with DOE's scientists, with the objective of transferring federally supported expertise to the private sector for commercial application. These assignments are cost shared with industry and involve both large and small companies. Support will also be provided for pilot laboratory initiatives to improve spin-off of federally funded R&D to U.S. industry.

The University Reactor Fuel Assistance activity provides support for refueling and related activities for university nuclear research and training reactors. The FY 1989 budget request will provide for refueling four reactors and will fund 23 reactor sharing research awards involving scientists from more than 50 universities. The request will also continue support for low-enriched uranium reactor fuel conversion as required by the Nuclear Regulatory Commission. This activity will be approximately at its midpoint by FY 1989 with 12 university reactors having received support for their reactor safety studies and four having received Commission approval for fuel conversion and startup.

The goal of the Energy Manpower Development activity is to increase the number of young people pursuing energy-related scientific and technical careers. The FY 1989 budget request will expand support for precollege science student and teacher programs sponsored by the laboratories. Six high school science student honors programs will be supported in FY 1989 at the Lawrence Livermore, Brookhaven, Lawrence Berkeley, and Oak Ridge National Laboratories, Fermi National Accelerator Laboratory, and the Pacific Northwest Laboratory. Over 2100 minority and female junior high school students will be supported through university grants under the Pre-Freshman Engineering program.

UNIVERSITY RESEARCH INSTRUMENTATION

The goal of this annual, competitive program is to strengthen the ability of universities to conduct long-range research on selected energy problems and processes by helping them to acquire the required state-of-the-art instrumentation. Another objective is to provide graduate students with hands-on experience in the use of sophisticated research equipment.

The University Research Instrumentation (URI) program, with a budget request of $5.0 million for FY 1989, complements the Department's energy research and technology programs. Generally, research grants and contracts provide support only for research operating costs, with funding for new equipment limited to instruments costing less than $30,000. The URI program assists universities in purchasing instruments costing over $100,000 that will be used by a number of researchers, including students.

Each year, the Department's program managers help select the high priority energy topic areas that are to be emphasized in the URI program announcement. The annual awards are based on merit, the accomplishments of current

DOE-supported research projects, and the degree to which the new equipment will enable researchers to substantially advance the understanding of energy-related phenomena. Since FY 1986, the URI program has emphasized support for innovative instrumentation, that is, equipment not generally available at U.S. universities. The FY 1989 request will continue this emphasis and will support about 18-20 instrumentation awards.

MULTIPROGRAM ENERGY LABORATORIES-FACILITIES SUPPORT

The Multiprogram Energy Laboratories-Facilities Support (MEL-FS) program aims to reduce deficiencies and to maintain safe, cost-effective and productive operations at the five national laboratories overseen by the Office of Energy Research. This is accomplished by supporting activities that counter problems of aging and obsolescence of facilities and of environmental compliance.

The FY 1989 budget request for MEL-FS is $65.9 million. Of that amount, $41.4 million is for the General Purpose Facilities Construction subprogram and $24.5 million is for the ORNL Environmental Compliance subprogram (Table 8).

The General Purpose Facilities Construction subprogram provides for rehabilitation and upgrading of deficient buildings, utilities, roads and other necessary facilities at the laboratories supported by the Office of Energy Research. The highest priority projects are those that address urgent environmental, health and safety deficiencies and those that can hamper or interrupt operations. The Construction request for this subprogram will continue 19 ongoing projects and initiate 14 new projects. The new projects

Table 8
Energy Supply R&D
Multiprogram Energy Laboratories - Facilities Support
Budget Authority
($ in millions)

	FY 1987	FY 1988	FY 1989 Request
General Purpose Facilities Construction			
Ongoing Projects	$ 23.7	$ 22.7	$ 29.8
New Projects	7.7	5.8	11.6
Total General Purpose Facilities	$ 31.4	$ 28.5	$ 41.4
Environmental Compliance-ORNL			
Operating Expenses	14.3	12.9	8.8
Capital Equipment	1.0	0.4	0.3
Construction	10.0	11.8	15.4
Total Environmental Compliance	$ 25.3	$ 25.1	$ 24.5
Total Multiprogram Energy Laboratories-Facilities Support	$ 56.7	$ 53.6	$ 65.9

include 2 environmental related projects, 1 road safety project, 2 fire protection projects, 3 utility projects and 6 building rehabilitation or replacement projects.

The ORNL Environmental Compliance subprogram originated in 1985 to address non-defense environmental deficiencies at Oak Ridge National Laboratory. This program will bring all operational systems up to current and expected environmental standards and will perform remedial actions necessary to clean up environmentally contaminated areas that are related to past ER activities.

Of the total $24.5 million Environmental Compliance request, $8.8 million is for Operating Expenses. This request will provide for assessments of the condition of operating systems and development of plans for needed upgrades. The Capital Equipment request of $0.3 million will provide equipment needed to support cleanup activities. The $15.4 million Construction request will provide funds to continue two high priority construction projects related to the liquid waste systems at ORNL.

ADVISORY AND OVERSIGHT PROGRAM DIRECTION AND POLICY AND MANAGEMENT

The FY 1989 budget request for Advisory and Oversight Program Direction is $3.3 million. The FY 1989 request will provide the staffing resources required by the Director of Energy Research to carry out his responsibilities under legislation (P.L. 95-91) and those assigned or delegated by the

Secretary in areas beyond the scope of other ongoing Energy Research programs. These funds are required to provide for the salaries, benefits, travel and other expenses associated with 44 full-time equivalents.

The FY 1989 budget request for Policy and Management is $0.7 million. These funds are required to provide for the salaries and related expenses associated with 8 full-time equivalents in the Office of the Director of Energy Research.

That concludes my statement. I would be happy to answer questions.

DISCUSSION

Mr. **Bruce**. Thank you, Dr. Decker. You state in your testimony that the research performed within the BES program leads to application. Clearly, the x-ray lithography initiative, which was included in the fiscal year 1988 program falls into that category.

Why has the DOE chosen not to include funds for this activity in the fiscal year 1989 budget?

Dr. **Decker**. The activities in x-ray lithography, which have been started in fiscal year 1988 with your direction, will continue on into fiscal year 1989 even though they are not called out specifically.

Mr. **Bruce**. What does that mean; without funds they will do that?

Dr. **Decker**. No. The people who are turning out work in that area will continue to carry out related programs on into 1989.

Mr. **Bruce**. The program will come to an end then. I mean, any researcher doing work in that area has to understand that if there is nothing in the fiscal year 1989 budget, there will be no follow on research; is that correct?

Dr. **Decker**. A lot of the effort that is going on is related to the primary work of the Basic Energy Sciences Program, and materials science and so forth. So, it is not a major diversion from some of our primary efforts. There is continuity for these researchers.

Mr. **Bruce**. Are you diverting funds? I mean, I am still unclear as to what happens if there is no funds for this program. Are you transferring funny money or transferring money? I am trying to figure out what happened to the program.

Dr. **Decker**. No. It is a choice of what we have scientists do in our materials program. A lot of what is being done for x-ray lithography in 1988 will continue under our materials program in 1989.

Mr. **Bruce**. What about the 3-percent growth in the Basic Energy Sciences Program budget; is that adequate to meet the needs as you perceive them?

Dr. **Decker**. There is no question but that our budget is very tight in this program. As I think you stated earlier in your remarks, it is a very difficult budget year for all of us and it's the best we can do under the circumstances.

Mr. **Bruce**. I am just curious. Where did you lose the battle, OMB, within your own scientific community; where was it that we got sidetracked and got limited to a 3-percent increase?

Dr. **Decker**. I don't know if I can point out a specific place where we were limited. The program, of course, always requests more money than we are able to come up with. It was just a total arrived at in general budget discussions within the Department and OMB.

Mr. **Bruce**. I think Congressman Fawell will have some questions on the photon generator. I wonder if you take a look at two areas, the Los Alamos Neutron Scattering Center, there is shortfall in their budget to continue operating at their current rate; and the Advanced Neutron Source for $5 million, as well as funds required to schedule other major facilities.

It didn't seem to me that DOE, in looking at your budget figures—I don't want to say didn't do an adequate job—but it seems to me the presentation would not have been very forceful or we wouldn't be facing the failure to meet basic needs at some of these research centers.

Dr. **Decker**. I think most of our research programs are very tight. I don't think that this is any exception.

Mr. **Bruce**. It is strictly budgetary?

Dr. **Decker**. Yes, sir.

Mr. **Bruce**. Perhaps we can go another round. Mr. Morrison, do you have questions?

Mr. **Morrison**. Thank you, Mr. Chairman. Dr. Decker, I am basically very pleased with your program. As I look at what you do is you make basic investments in energy sciences on behalf of all of us through using both the university and the National Lab programs. Those have to be sound investments and it appears to me that you have a very good track record.

I congratulate you for that. In fact, your programs have been so good that you have gotten some special attention and a few folks added a few things last year knowing that you did a good job. Would you care to comment on some of the Congressional initiatives that we added in last year's continuing resolution.

Have they worked out or what is the status of some of those efforts?

Dr. **Decker**. We certainly followed all of the Congressional initiatives that were written into the law. I think that we have put together a decent program in x-ray lithography and certainly made good use of additional funds in high-temperature superconductivity.

I think those in the research program have worked out. They have been difficult to accommodate because most of them did not have additional funds associated with them, so there has had to be a fair amount of redirecting work at our contractor sites to accommodate the Congressional directions.

Mr. **Morrison**. I can see that they could be disrupting to your planning. Did your office initiate the new appropriation account we have now for the user facilities?

Dr. **Decker**. No, sir.

Mr. **Morrison**. Where did that come from?

Dr. **Decker**. It was initiated by the Office of Management and Budget.

Mr. **Morrison**. Would you comment on the status of the High Flux Isotope Reactor, a start-up date, problems, or do you have those all under control at the moment?

Dr. **Decker**. The High Flux Isotope Reactor has been in a standdown condition since November of 1986 for two reasons. First, we had a technical problem associated with embrittlement of the pressure vessel at a time sooner than we had expected. The second type of problem that we have has been with the management and quality assurance by the contractor.

We have gone through a number of technical reviews on the embrittlement problem. I pulled together a committee that was chaired by Joe Hendrie, former NRC Commissioner and looked at by the National Academy of Sciences recently, and I think the conclusions that are coming out are that this reactor is safe to operate technically for probably up to another 10 years.

The management and quality assurance problems that I mentioned are being sorted out by the contractor, and we would hope that we would be able to restart the reactor in July.

Mr. Morrison. You have a new proposal on the project that I mentioned in my opening statement that we are sort of excited about out our way. Will you comment on the procedure that you are going to utilize in evaluating the Molecular Science Research Center?

Dr. Decker. Yes, sir. We have just received a proposal from PNL for that center for a significant initiative. We intend to peer review that proposal and consider funding it in the 1990 budget request.

Mr. Morrison. What impact would it have if we gave you a little head start on that date?

Dr. Decker. I suppose it would make it come into being earlier.

Mr. Morrison. We will be very interested in working with you.

Dr. Decker. I think that the activities that are envisioned in that center have been building up slowly for a time over a last couple of years as the Laboratory has proposals. They have competed favorably with other competition and slowly that activity is building up.

Mr. Morrison. Thank you very much.

Mr. Bruce. Thank you, Mr. Morrison. Mr. Fawell.

Mr. Fawell. Thank you, Mr. Chairman. Dr. Decker, as you might suspect, I might have an inquiry about the Advanced Photon Source. We are very excited about that in our area at Argonne Lab. In fact, I was at a meeting of some 300, I believe, users who were tremendously enthused. There were nothing but positive comments in regard to all of that DOE has done to bring this to fruition.

The only area that there was some questions constantly put to me was the fact that—you might guess that this has something to do with money—construction schedule at $6 million for 1989, a number of people and the users especially expressed to me that this is going to take so long to build that we all may have long beards and be out of the profession by the time that it actually culminates over an eight-year construction schedule.

Am I correct in that regard, and if so, what possibility is there that some additional funds might be found here so that a more economically efficient construction schedule could be created?

Dr. Decker. Our budget number of $6 million was clearly constrained by the budget targets that we had to work with. I think that while this is not as much as the Laboratory we would like, it is at least a start on the project.

Hopefully, we will get encouragement of the really excellent team that is going to be assembled by Argonne. I would hope the project can proceed on a reasonable construction schedule.

Mr. Fawell. What is that construction schedule as you see it right now, amortized over how many years?

Dr. Decker. It is six to seven years on the current schedule.

Mr. Fawell. The total construction cost is estimated to be what at this point?

Dr. Decker. I believe it is $456 million.

Mr. Fawell. Just as Congressman Morrison had indicated a hope that perhaps we could manufacture dollars out of the sky or something if anything possibly could be done there.

Mr. Morrison. That's the Subcommittee that just left, I might add. [Laughter.]

Mr. Fawell. I don't want my comments to dampen the enthusiasm in the praise that we have for DOE for that very fine advancement in science. I am going to try to peer into every corner and see if maybe there may be some extra dollars here and there that could move it along a bit more.

Thank you very much. I have no further questions.

Mr. Bruce. Thank you, Mr. Fawell. I am just curious about one other program; Nuclear Engineering Education. We authorized $5 million last year. For more than two years, witnesses have come before this Subcommittee indicating the really distressed nature of that particular area and need for infusion of Federal dollars.

This year you have zeroed that budget line item out. Do you know something that we don't know?

Dr. Decker. The 1988 budget with the $5 million that Congress put in, came to us after our 1989 budget had essentially been put to bed. It is impossible for us to go back in. What we have done is to start 10 fellowships from $800,000 of the $5 million on fellowships that will be three-year grants. The remainder of the money will essentially go into nuclear engineering research, the other part of the direction that you gave us.

Mr. Bruce. But again, what happens in fiscal year 1989? You say the money we gave you last year you are starting to spend this year, and if we don't appropriate something this year then the program has to come to an end. Any researcher has to take a look at it and realize that DOE has not requested money, we have not put it in, and it's over with, isn't it?

Dr. Decker. The way that the grants are being written, such that they carry through fiscal year 1989, to give us a chance to pick it up in 1990.

Mr. Bruce. Thank you very much, Dr. Decker. If there are no other questions of Dr. Decker, we will excuse you and start on with Dr. Sproull.

[Questions and answers for the record for Dr. Decker follow:]

BASIC ENERGY SCIENCES

Question 1: Are some funds within the BRUF account directly linked to specific BES program activities, such as high temperature superconductivity research?

Answer: No. The funds within the BRUF account are to be used only for the operation including fuel in the case of the reactors, maintenance, outfitting and construction or upgrade, of the listed facilities. At times, the operating parameters of a given facility may be chosen so as to develop data specifically needed by a research user or special facility studies may be carried out to provide data for a project still on the research account. In the great majority of these special cases, the facility may still be used by other research users so all facility costs will continue to be borne by BRUF.

BASIC ENERGY SCIENCES

Question 2: Is there a reimbursement account that provides funds to operate the major user facilities? -- If so, how large is it and how it is administered?

Answer: No, there is not a separate reimbursement account for the operation of the major user facilities. The funds to operate these facilities are provided in the appropriation provided by Congress for the Basic Research User Facilities (BRUF).

BASIC ENERGY SCIENCES

Question 3: The BES program serves to provide new ideas, knowledge and techniques that hopefully will enhance an international competitiveness, leading to new marketable products and expanded energy resources. -- Are there programs designed specifically to transfer BES derived accomplishments to industry?

Answer: There are many different types of technology transfer programs available to move BES derived accomplishments to industry. The BES research at the DOE laboratories is specifically designed to underpin the various DOE applied programs and is, in many cases, co-located with these programs so as to enhance the technology transfer. Thus, at one location, for example, BES supported research on radiation effects is co-located with nuclear energy research aimed at developing alloys more resistant to radiation damage. The basic principles of radiation effects have been incorporated into a new highly radiation resistant alloy for liquid fast reactors now being produced by industry. This is the most common method for transfer of BES derived accomplishments, and many more such examples can be cited. In order to communicate these results to the DOE technology programs, workshops and review meetings are a normal method of operation, together with publications. Another method for technology transfer is the method for support of large unique facilities. These facilities are set up to be user facilities and serve as a focal point for bringing together DOE laboratories, universities and industry. They work together on common problem areas using the DOE expertise in constructing and operating large accelerator or reactor facilities. An example of this type of technology transfer is the x-ray lithography area. At the National Synchrotron Light Source, companies such as IBM have been utilizing the unique radiation produced there to develop the next generation of semiconductor integrated circuits.

Each laboratory has a technology transfer program and most of the laboratories have set up specific organizations to market the output of the DOE research including the BES accomplishments. At Argonne National Laboratory, for example, an organization, ARCH (Argonne/Chicago) has been set up to specifically interact with industry. This organization is taking a lead role in the area of high temperature superconductivity, having recently signed an agreement with a company to transfer the Argonne (BES supported) materials processing knowledge. Where appropriate, a DOE laboratory researcher may be granted the patent rights to an invention and is free to set up his own company. Recently, a BES-supported researcher at Sandia discovered a new way to clean automobile exhaust gases and has set up his company to pursue the commercialization of this discovery.

Within BES, there are located two programs of special note with regard to technology transfer. The Advanced Energy Projects subprogram was specifically set up to support projects which either do not fit in other DOE programs or need to be researched for technical feasibility first. The subprogram then, after a few years of support, tries to find a home either in DOE or the private sector for these developments. In one case, for example, an outgrowth of this support has been a company which produces a new type of cryogenic cooling device.

The Small Business Innovative Research program which is mandated by law and is DOE-wide is managed within the BES program. It also provides another avenue for BES or other derived ideas to be pursued by the private sector at small businesses.

In summary, there are many programs available for technology transfer of BES derived accomplishments. The exact method has to be tailored to the nature of the discovery.

Basic Energy Sciences

Question 1: What has been the overall impact on the BES programs of the "Congressional Initiatives" contained in the FY 1988 Continuing Resolution?

Answer: In those instances in which the Congressional direction included specific funds to cover the direction, the impact was neutral. However, many of the directives in the operating funds area did not include specific funds to cover the directed spending. In each of these cases, significant redirection in program scope was required. This redirection overall has been detrimental to the long range BES research program where long term commitments are required to obtain the maximum benefit from the government investment.

BASIC ENERGY SCIENCES

Question 2: The FY 1988 Continuing Resolution included $10 million "to initiate a technology program in X-ray lithography aimed at restoring U.S. leadership in the manufacture of high density computer chips." How is DOE carrying out this directive, and how is it impacting the base programs in synchrotron radiation at Brookhaven National Laboratory, Lawrence Berkeley Laboratory, Stanford Synchrotron Radiation Laboratory, Argonne National Laboratory, and at any other DOE national laboratory?

Answer: The directive in the FY 1988 Continuing Resolution to spend $10 million "to initiate a technology program in X-ray lithography aimed at restoring U.S. leadership in the manufacture of high density computer chips" was implemented by redirecting $10 million from existing programs at Brookhaven National Laboratory (BNL), Argonne National Laboratory (ANL), Lawrence Berkeley Laboratory (LBL), and Oak Ridge National Laboratory (ORNL). BNL coordinates this multi laboratory X-ray lithography project. The principal effects on the synchrotron radiation program are at BNL where a superconducting compact synchrotron for X-ray lithography is being designed in collaboration with industry at the expense of support to other BNL research areas. Also, the National Synchrotron Light Source (NSLS) at BNL will be used to conduct experiments in machine physics to support the design of the compact synchrotron. Operation support for X-ray lithography at NSLS will be increased at the expense of other synchrotron research. Research at ANL in electron microscopy of materials and in surface chemistry and physics was redirected to support the X-ray lithography program in the areas of masks, substrates, and photon-surface interactions. At LBL, research on ceramic-metal interfaces and semiconductors was redirected to address problems in high-density computer chips produced by X-ray lithography. At ORNL, research in ion implantation was redirected to study problems in X-ray lithography such as correcting breaks in patterns of high-density computer chips. The Stanford Synchrotron Radiation Laboratory is not involved in this project.

BASIC ENERGY SCIENCES

Question 3: Did the Office of Energy Research propose the new appropriation account titled "Basic Research User Facilities (BRUF)"?

Answer: The proposal for a separate appropriation for facilities was originally suggested by OMB but it was thoroughly discussed with DOE management.

BASIC ENERGY SCIENCES

Question 4: What is the rationale for commingling BES, high energy physics and nuclear physics facilities and SSC funds within the BRUF account? Does DOE expect to be able to move funds among all these facilities?

Answer: The intent of presenting all of the major user facilities in a single budget is not to commingle funds between the facilities. Each of the BRUF program areas whether Basic Energy Sciences, Nuclear Physics, High Energy Physics, or Superconducting Super Collider would retain its separate identity. The programs within the new BRUF appropriation will be subject to the same fund controls as the individual programs within the traditional DOE appropriations, e.g., Energy Supply Research and Development, General Science and Research, etc.

BASIC ENERGY SCIENCES

Question 5: The FY 1988 Continuing Resolution included $11.7 million "to be made available to continue the ongoing program at the Florida State University supercomputer center." How is DOE carrying out this directive, and how is it impacting the Applied Mathematical Sciences Program?

Answer: DOE has followed the direction of the Congress and has provided funds to Florida State University as part of the five year cooperative agreement. To carryout this direction, planned activities in each of the subprograms within BES, including Applied Mathematical Sciences, were curtailed. This reduction to planned activity is counterproductive to both Congressional, as well as Administration, intentions.

BASIC ENERGY SCIENCES

Question 6: The Committee has received information to the effect that there are major problems with the operation of the Los Alamos Neutron Scattering Center. Please explain the nature of these problems, and what funds will be needed to correct them.

Answer: The Proton Storage Ring (PSR), which was constructed as a Defense Program project, is capable of delivering only 30 microamps of protons to the LANSCE target in a manner which allows hands-on maintenance. At higher currents, the beam losses cause irradiation of ring components and precludes proper maintenance. The principal reason for the beam losses can be traced to the injection scheme used. In order to achieve the higher current desired, it will be necessary to change the manner of injection and increase the beam aperture at the extraction point. Furthermore, improvements in collimation and beam diagnostics are also needed. The costs associated with this modification range from about $6.5M to about $8.7M over the next 2 to 3 years. This corrective action has still to be reviewed in depth and the appropriate Office to carry the project has yet to be decided.

BASIC ENERGY SCIENCES

Question 7: What is the status of the High Flux Isotope Reactor at Oak Ridge? When is the expected start-up date?

Answer: The High Flux Isotope Reactor (HFIR) has been down since November 1986. Many studies and analyses of the reactor have been undertaken and essentially are all completed. As a result of these studies, a plan has been established to restart the reactor. This plan involves operating the reactor at a lower power level than previously (85 megawatts instead of 100 megawatts), a lower pressure and higher temperature. This will allow the present pressure vessel to be used for at least 10 more years. A hydrostatic overpressure of the vessel will be performed annually with an instrumented test to determine the vessel integrity. The first test was completed successfully in August 1987. A probabilistic risk assessment of the reactor was completed and the result shows that HFIR falls into the lowest risk category. Safety related recommendations for hardware and procedures have been or are planned to be installed at HFIR. The management of the reactors at Oak Ridge has been completely reorganized to improve the operational and safety procedures. The most important remaining task is the quality assurance upgrade program. All of the work done at the laboratory is now in the process of being reviewed prior to restart. The DOE reactor safety review will occur in late spring/early summer. A tentative schedule for restart has been established for late summer, but is highly dependent on the outcome of the reviews.

BASIC ENERGY SCIENCES

Question 8: What is the status of the high-enriched uranium target for the Intense Pulsed Neutron Source at Argonne? When will it be installed, and will the funds requested for FY 1989 allow for sufficient running time so that the target will be "self-protecting"?

Answer: The enriched uranium disks for the IPNS booster target have been completed at Y-12 in Oak Ridge. This includes casting, machining, bonding with zircalloy, quenching to refine grain size, final machining and testing. The Safety Analysis Report was submitted to DOE in April after receiving approval from an Argonne Safety Committee. The final assembly and insertion of the target is scheduled for July - August 1988, with the first beam on target scheduled for the middle to end of August. In order to remain self-protecting, IPNS must run approximately 50 percent of the time. If the activity falls below the self-protecting level, considerable expense is involved in security costs. Computer calculations indicate that the minimum operation for FY 1989 is 23 weeks. The user program and in-house research effort will have to be adjusted as necessary to accommodate this operational requirement.

BASIC ENERGY SCIENCES

Question 9: On page 12 of your testimony, you mention the production of einsteinium-253 and fermium-255 in the High Flux Isotope Reactor and the Transuranium Processing Plant at Oak Ridge. Can these isotopes be produced at any existing facility, either public or private, in the U.S.? Could they be produced at the Fast Flux Test Facility at Hanford?

Answer: Approximately twenty years ago a few grams of Californium-252 were produced in the production reactors at Savannah River. However, that would not be feasible today. Currently, Hanford and Oak Ridge National Laboratory staff are collaborating in the study of the possibility of production of the transuranium isotopes at the FFTF. Although there are uncertainties due to inadequate data, it appears that the FFTF could be used to produce useful quantities of isotopes up to einsteinium but probably not fermium and beyond.

However, there needs to be additional effort to determine the cost and impact of shifting production from HFIR to FFTF. Unresolved questions include the lack of a Transuranic Processing Plant at Hanford and the losses of short lived isotopes during the time interval between cessation of irradiation and completion of chemical processing if shopment back to Oak Ridge is required. Thus, while the irradiations and the subsequent chemical separation can be carried out at different locations, their relative locations are important in determining the ultimate quantity and cost of the product.

No other reactors, public or private, in the Western World can produce these isotopes in useful quantities.

BASIC ENERGY SCIENCES

Question 10: The February 12, 1988, "Holifield Tables" indicate that the "A/S REQ" for FY 1989 for the Basic Energy Sciences Program totalled $566.45 million, including $458.751 million for operating expenses and $107.699 million for plant and capital equipment. According to these tables, the Department's FY 1989 request to OMB totalled $516.145 million, including $430.745 million for operating expenses and $85.4 million for plant and capital equipment.

a. What are the specific differences between these two budgets?

Answer: The primary difference between the "A/S Request" and the budget that was submitted to OMB was that the department's enhanced request represented a desired budget level that was unconstrained by overall Department budget targets. This level would permit expansion in each of the highest priority BES research areas and would permit the start of either new construction projects or enhanced funding to projects in the target budget case.

In addition, several selected key issues could be addressed in the enhanced internal budget level that could not be funded in a target level budget. These issues included funding to continue the Florida State Supercomputer cooperative agreement, funding to address improvements needed at the HFIR Reactor, and enhanced funding for priority research areas including, among others, superconductors, semiconductors and the geosiences.

Question 10b. What, if any, differences exist between the Department's request to OMB, and the budget submitted to Congress?

Answer: The primary difference between the request to OMB and the request to Congress is that OMB directed that $7.1M be made available to address deficiencies at the HFIR reactor within the total requested by DOE. In addition, the decision was made to include major user facilities in a new appropriation account entitled "Basic Research User Facilities (BRUF)" which would be separate from the appropriation requested for research.

BASIC ENERGY SCIENCES

Question 11: Please identify all unobligated balances in the Basic Energy Sciences Program.

Answer: The total amount of unobligated balances in Basic Energy Sciences Program is $230,286. This amount is less than .001 of a percent of the total available to the BES program.

SUPPORTING RESEARCH AND TECHNICAL ANALYSIS

Question 12: The February 12, 1988, "Holifield Tables" indicate that the "A/S REQ" for FY 1989 for the Energy Research Analysis Sciences Program totalled $3.85 million for operating expenses. According to these tables, the Department's FY 1989 request to OMB totalled $3.8 million for operating expenses.

a. What are the specific differences between these two budgets?

Answer: There is no difference in content; the $50,000 difference in amount is due to rounding.

Question 12b. What, if any, differences exist between the Department's request to OMB, and the budget submitted to Congress?

Answer: There is no difference.

BASIC ENERGY SCIENCES

Question 13: Please identify all unobligated balances in the Energy Research Analysis Program.

Answer: The total amount of unobligated balances in the Energy Research Analysis Program is $250,240.

UNIVERSITY RESEARCH INSTRUMENTATION

Question 14: The February 12, 1988, "Holifield Tables" indicate that the "A/S REQ" for FY 1989 for the University Research Instrumentation Program totalled $5.0 million for operating expenses. According to these tables, the Department's FY 1989 request to OMB also totalled $5.0 million for operating expenses.

a. What, if any, differences exist between these two budgets?

Answer: There are no differences between these two University Research Instrumentation budgets.

Question 14b. What, if any, differences exist between the Department's request to OMB, and the budget submitted to Congress?

Answer: There are no differences between these budget submissions either.

UNIVERSITY RESEARCH INSTRUMENTATION

Question 15: Please identify all unobligated balances in the University Research Instrumentation Program.

Answer: The FY 1987 unobligated balance for University Research Instrumentation was $28,748. This amount had been set aside for a publication which was delayed and has since been accomplished.

UNIVERSITY RESEARCH SUPPORT

Question 16: The February 12, 1988, "Holifield Tables" indicate that the "A/S REQ" for FY 1989 for the University Research Support Program totalled $15.77 million for operating expenses. According to these tables, the Department's FY 1989 request to OMB also totalled $15.77 million for operating expenses.

a. What differences, if any, exist between these two budgets?

Answer: There are no differences between these two University Research Support budgets.

Question 16b. What, if any, difference, exist between the Department's request to OMB, and the budget submitted to Congress?

Answer: These budget submissions were also identical.

UNIVERSITY RESEARCH SUPPORT

Question 17: Please identify all unobligated balances in the University Research Support Program.

Answer: The FY 1987 unobligated balance for University Research Support was $46,472, and is currently being utilized to fund ongoing, priority efforts in the program.

ADVISORY AND OVERSIGHT PROGRAM DIRECTION

Question 18: The February 12, 1988, "Holifield Tables" indicate that the "A/S REQ" for FY 1989 for the Advisory and Oversight Program Direction totalled $3.65 million for operating expenses. According to these tables, the Department's FY 1989 request to OMB totalled $3.35 million for operating expenses.

a. What are the specific differences between these two budgets?

Answer: The "A/S REQ" for FY 1989 for Advisory and Oversight Program Direction totalled $3.65 million for operating expenses to provide for the salaries, benefits, travel, and other associated costs of 48 full-time equivalents (FTE's). The Department disallowed a request for 4 additional FTE's above the FY 1988 level, therefore, the FY 1989 request to OMB of $3.35 million for operating expenses reflected a reduction of 4 FTE's and associated costs of $.3 million to a level of 44 FTE's.

Question 18b: What are the specific differences between these two budgets and the Department's request of $3.339 million submitted to Congress?

Answer: The Department's request of $3.339 million submitted to Congress supports 44 FTE's as in the request to OMB, but reflects a reduction of $11,000 in personnel benefits based on revised estimates of the impact of the new Federal Employees Retirement System (FERS).

ADVISORY AND OVERSIGHT PROGRAM DIRECTION

Question 19: Please identify all unobligated balances in the Advisory and Oversight Program Direction account.

Answer: The FY 1987 unobligated balances in the Advisory and Oversight Program Direction account in FY 1988 total $220,086. These funds will be used to fund the FY 1988 general pay raise and to provide required program support such as printing, small purchases of supplies and materials, communications and information services including reimbursement of the Office of Scientific and Technical Information for services provided, and other contractual support required by limited staffing resources.

MULTIPROGRAM ENERGY LABORATORIES-FACILITIES SUPPORT

Question 20: The February 12, 1988, "Holifield Tables" indicate that the "A/S REQ" for FY 1989 for the Multiprogram Energy Laboratories-Facilities Support Program totalled $65.875 million, including $10.67 million for operating expenses and $55.205 million for plant and capital equipment. According to these tables, the Department's FY 1989 request to OMB also $65.875 million, including $10.67 million for operating expenses and $55.205 million for plant and capital equipment.

a. What, if any, differences exist between these two budgets?

Answer: There are no differences between these two Multiprogram Energy Laboratories - Facilities Support Program budgets.

Question 20b. What are the specific differences between these two budgets and the Department's FY 1989 budget submission to Congress, which also requests a total of $65.875 million, but instead includes $8.77 million for operating expenses and $57.105 million for plant and capital equipment?

Answer: The Congressional submission for the Multiprogram Energy Laboratories - Facilities Support Program budget differed from the OMB submission. Specifically, the FY 1989 request to OMB proposed expanding the Environmental Compliance subprogram beyond its original intent of being devoted to the Oak Ridge National Laboratory. This budget proposed to initiate environmental compliance activities at all Energy Research multiprogram laboratories. In so doing, it included operating expense funds for other laboratories to investigate areas of environmental noncompliance and initiation of environmental upgrade construction projects. It was decided that the Environmental Compliance subprogram should be kept separate and only include Oak Ridge National Laboratory. Therefore, funds, within the same program total, were redistributed to environmental related construction projects in the General Purpose Facilities subprogram, as has been done in the past, for the Congressional submission.

MULTIPROGRAM ENERGY LABORATORY - FACILITIES SUPPORT

Question 21: Please identify all unobligated balances in the Multiprogram Energy Laboratories - Facilities Program account.

Answer: The FY 1987 unobligated balance for the Multiprogram Energy Laboratories - Facilities Support Program was $22,748. This amount has been restored to the various projects it was intended for in order to continue and/or complete the planned activities.

BASIC ENERGY SCIENCES

Question 22: For FY 1987 - FY 1989, please provide the information requested in a. - e. below for the Intense Pulsed Neutron Source at Argonne National Laboratory.

a: Actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, capital equipment, general plant projects, accelerator improvement projects, and any other funding attributable to the facility. Please indicate the sources of the funds (i.e., Basic Energy Sciences, Nuclear Physics, High Energy Physics, etc.).

Answer:

ALL FUNDS IN $K

Argonne Funds	FY 1987	FY 1988	FY 1989
IPNS operations (BES)	4,981	5,000	5,420
In-house Research (BES)	1,700	1,825	1,840
Capital Equipment (BES)	630	760	788
Lab Discretionary	320	250	150
DOD - SDI for Neutral Particle Beam (Net of additional operating expenses)	1,100	650	0
GPP	0	155	0
AIP	0	0	0
TOTAL	8,731	8,640	8,198
Out-of-House Research			
Universities, Other Government Labs, Industry, Foreign, etc., TOTAL	3,550	3,875	4,250

Question 22b: Actual and estimated staffing levels

Answer:

	FY 1987	FY 1988	FY 1989
STAFFING LEVELS	52	50	48

Question 22c: Actual and estimated utilization of the facility, and physical maximum of utilization of the facility.

Answer:

With sufficient dollars a number of the facilities which the Department runs, including IPNS, could be physically operated longer; however, choices have been made according to importance of the research. The Department believes that this is an efficient and effective level of operation. The number of physical hours the facility could be operated would be 5,450 hours.

Question 22d: Level of funding required to achieve the optimal level of utilization of the facility.

Answer: It is estimated that operation of IPNS at the physical maximum of utilization, 32 weeks, in FY89 would cost approximately $6850K, which is $1430K more than the $5420K in the President's budget for IPNS. The additional funds are for electricity, materials and services, operating staff, and technical support for the instruments and user program.

Question 22e: Additional research funding required to support the optimal level of utilization of the facility.

Answer: Additional research funds are required for physical maximum use of the facility for proper in-house research during the extra operation and for the increase in user assistance. This would be a mixture of Ph.D. staff and post-docs and research funds required are estimated at $600K.

BASIC ENERGY SCIENCES

Question 23: For FY 1987 - FY 1989, please provide the information requested in a. - e. below for the High Flux Beam Reactor at Brookhaven National Laboratory.

a: Actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, capital equipment, general plant projects, accelerator improvement projects, and any other funding attributable to the facility. Please indicate the sources of the funds (i.e., Basic Energy Sciences, Nuclear Physics, High Energy Physics, etc.)

Answer:

ALL FUNDS IN $K

Brookhaven Funds (BES except as indicated)	FY 1987	FY 1988	FY 1989
Operating Expenses	9,959	10,900	11,545
Capital Equipment	40	60	60
Construction - ARAM	440	340	350
Construction - GPP	460	0	800
In-House Research	5,260	5,905	6,070
BES	3,380	3,950	4,090
Nuclear Physics	700	655	680
Biology & Env. Research	1,180	1,300	1,300
TOTAL	21,419	23,110	24,895
Out-of-House Research			
Universities, Other Government Labs, Industry, Foreign, etc., TOTAL	4,380	4,900	5,060

Question 23b: Actual and estimated staffing levels

Answer:

	FY 1987	FY 1988	FY 1989
STAFFING LEVELS (FTES)	65	66	68

Question 23c: Actual and estimated utilization of the facility, and optimal level of utilization of the facility.

Answer:

With sufficient dollars a number of the facilities which the Department runs, including HFBR, could be physically operated longer; however, choices have been made according to importance of the research. The Department believes that this is an efficient and effective level of operation. The number of physical hours the facility could be operated would be 6,500 hours.

Question 23d: Level of funding required to achieve the optimal level of utilization of the facility.

Answer: **The increase in operating expenses required to reach the physical maximum of use of the facility would be $1.4M in FY 1989.**

Question 23e: Additional research funding required to support the optimal level of utilization of the facility.

Answer: Additional research funds are required for the physical maximum use of the facility for proper in-house research during the extra operation and for the increase in user assistance. This would be a mixture of Ph.D. staff and post-docs and research funds required are estimated at $1.3M.

BASIC ENERGY SCIENCES

Question 24: For FY 1987 - FY 1989, please provide the information requested in a. - e. below for the National Synchrotron Light Source at the Brookhaven National Laboratory.

a: Actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, capital equipment, general plant projects, accelerator improvement projects, and any other funding attributable to the facility. Please indicate the sources of the funds (i.e., Basic Energy Sciences, Nuclear Physics, High Energy Physics, etc.)

Answer:

ALL FUNDS IN $K

Brookhaven Funds (BES)	FY 1987	FY 1988	FY 1989
Operating Expenses	18,524	19,625	20,285
Capital Equipment	875	550	550
Construction - AIP	2,015	1,960	1,230
Construction - GPP	400	685	500
In-House Research	6,660	7,700	8,800
TOTAL	28,474	30,520	31,365
Out-of-House Research			
Universities, Other Government Labs, Industry, Foreign, etc. TOTAL	12,800	16,400	22,300

Question 24b: Actual and estimated staffing levels

Answer:

	FY 1987	FY 1988	FY 1989
STAFFING LEVELS (FTES)	197	207	201

Question 24c: Actual and estimated utilization of the facility, and optimal level of utilization of the facility.

Answer:

With sufficient dollars a number of the facilities which the Department runs, including NSLS, could be physically operated longer; however, choices have been made according to importance of the research. The Department believes that this is an efficient and effective level of operation. The number of physical hours the facility could be operated would be 7,000 hours.

Question 24d: Level of funding required to achieve the optimal level of utilization of the facility.

Answer: The additional operating expenses needed to achieve the physical maximum of use of the facility would be $3M.

Question 24e: Additional research funding required to support the optimal level of utilization of the facility.

Answer: Additional research funds are required for the physical maximum use of the facility for proper in-house research during the extra operation and for the increase in user assistance. This would be a mixture of Ph.D. staff and post-docs and research funds required are estimated at $1.2M.

BASIC ENERGY SCIENCES

Question 25: For FY 1987 - FY 1989, please provide the information requested in a. - e. for the Los Alamos Neutron Scattering Center (LANSCE) at the Los Alamos National Laboratory.

a: Actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, capital equipment, general plant projects, accelerator improvement projects, and any other funding attributable to the facility. Please indicate the sources of the funds (i.e., Basic Energy Sciences, Nuclear Physics, High Energy Physics, etc.)

Answer:

	FY 1987	FY 1988	FY 1989
LANSCE-PSR Operations (BES)	1,300	3,000	3,100
In-house Research (BES)	2,088	2,088	2,144
Capital Equipment (BES)	600	600	600
LANSCE-PSR Operations (LANL)	8,400	7,300	6,200
In-house Research (LANL)	1,500	1,500	1,600
Capital Equipment (LANL)	900	300	2,500
TOTAL	14,788	14,788	16,144

Out-of-House Research

LANSCE construction project will be completed in FY 1990 at which time it will be open for general users. Outside users are expected to be about three times the in-house users.

Question 25b: Actual and estimated staffing levels.

Answer:

	FY 1987	FY 1988	FY 1989
STAFFING LEVELS	71.6	66.9	79.0

Question 25c: Actual and estimated utilization of the facility, and optimal level of utilization of the facility.

Answer:

With sufficient dollars a number of the facilities which the Department runs, including LANSCE, could be physically operated longer; however, choices have been made according to importance of the research. The Department believes that this is an efficient and effective level of operation. The number of physical hours the facility could be operated would be 4,800 hours.

Question 25d: Level of funding required to achieve the optimal level of utilization of the facility.

Answer: The additional funding required to operate at the physical maximum is $1.5M.

Question 25e: Additional research funding required to support the optimal level of utilization of the facility.

Answer: Additional research funds are required for the physical maximum use of the facility for proper in-house research during the extra operation and for the increase in user assistance. This would be a mixture of Ph.D. staff and post-docs and research funds required are estimated at $1M.

BASIC ENERGY SCIENCES

Question 26: For FY 1987 - FY 1989, please provide the information requested in a. - e. below for the High Flux Isotope Reactor and the Transuranium Processing Plant at the Oak Ridge National Laboratory.

a: Actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, capital equipment, general plant projects, accelerator improvement projects, and any other funding attributable to the facility. Please indicate the sources of the funds (i.e., Basic Energy Sciences, Nuclear Physics, High Energy Physics, etc.).

Answer: The information requested is given below first for the High Flux Isotope Reactor and then the Transuranium Processing Plant at the Oak Ridge National Laboratory.

ALL FUNDS IN $K

High Flux Isotope Reactor (HFIR)*

	FY 1987	FY 1988	FY 1989
Operations - BES	10231	15600	16383
Capital Equipment and Fuel	1169	900	500
Operations-JAERI-Fusion+Other	0	1446	2000
General Plant Project	0	135	1065
Subtotal	11400	18081	19948
In-House DOE Research			
BES Chemical Sciences	2806	2957	2929
BES Materials Sciences	1310	1391	1376
NE	350	1300	1500
MFE	400	470	295
Subtotal	4866	6118	6100
Non-DOE Research			
NSF	637	285	865
JAERI-Neutron Scattering	105	120	165
JAERI-Fusion	700	1000	500
JAERI-Nuclear Energy	335	495	760
Subtotal	1777	1900	2290
Other Users (Estimated Research Support) University Guests, Industry, Other Government Labs, Foreign Guests	571	600	5040
Total	18614	26699	33378

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*Assumes summer 1988 restart after being down since November 1986 to analyze and correct operational problems.

Transuranium Processing Plant (TPP)

	FY 1987	FY 1988	FY 1989
Operations - BES	6435	7185	7330
Capital Equipment	38	365	405
Subtotal	6473	7550	7735
In-House Research (ORNL)	1310	1361	1376
Out-of-House Research (Other Sites)	4560	4720	4750
Total	12343	13631	13861

Question 26b: Actual and estimated staffing levels.

Answer:

	FY 1987	FY 1988	FY 1989
HFIR Facility Staffing	90.5	114.5	118
TPP Staffing	49.1	60.1	61.6

Question 26c: Actual and estimated utilization of the facility, and optimal level of utilization of the facility.

Answer:

With sufficient dollars a number of the facilities which the Department runs, including HFIR and TPP, could be physically operated longer; however, choices have been made according to importance of the research. The Department believes that this is an efficient and effective level of operation. The number of physical hours the facility could be operated would be 7,900 hours for HFIR and 6,550 hours for TPP.

Question 26d: Level of funding required to achieve the optimal level of utilization of the facility.

Answer:

	FY 1987	FY 1988	FY 1989
HFIR Level of Funding Required to Achieve the Physical Maximum (ER + Other Users)	0	19600	19700
TPP Level of Funding Required to Achieve the Physical Maximum Utility of Facility	0	8709	9159

Question 26e: Additional research funding required to support the optimal level of utilization of the facility.

Answer:

	FY 1987	FY 1988	FY 1989
HFIR Additional Research (ER) Funding Required to Support the Physical Maximum	0	0	300
TPP Additional Research (ER) Funding Required to Support the Physical Maximum	0	1500	1500

BASIC ENERGY SCIENCES

Question 27: For FY 1987 - FY 1989, please provide the information requested in a. - e. below for the Combustion Research Facility at the Sandia National Laboratories - Livermore.

a: Actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, capital equipment, general plant projects, accelerator improvement projects, and any other funding attributable to the facility. Please indicate the sources of the funds (i.e., Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).

Answer: Facility operations is funded entirely by the Division of Chemical Sciences, Office of Basic Energy Sciences (BES). In-house research is supported by the Department of Energy (DOE) through BES, the Office of Conservation, the Office of Fossil Energy, and the Office of Military Applications (Defense Programs). Non-DOE in-house research is supported by the Department of Defense (DoD), NASA, and by Sandia internal research and development funds (IR&D). Out-of-house research is supported by the Gas Research Institute (GRI) and the Electric Power Research Institute (EPRI). This category also includes industrial and academic "in-house" support costs, which are our estimates of equipment loans to the Combustion Research Facility (CRF), and salaries paid to visiting scientists by their home institutions. General plant project (GPP) and capital equipment funding are listed along with Facility Operations and In-house Research, respectively. No accelerators are in use at the CRF; consequently, no accelerator improvement projects have occurred and none are planned.

ALL FUNDS IN $K

	FY 1987	FY 1988	FY 1989
Operations - BES	3540	3510	3580
Capital Equipment - BES	675	665	710
Capital Equipment - Conservation	125	90	250
General Plant Project	0	400	400
In-House Research			
BES	3289	3466	3444
Conservation	2100	2350	2500
Fossil	1030	1035	1500

	FY 1987	FY 1988	FY 1989
Defense Programs	1875	675	675
DoD	675	750	825
NASA	150	120	120
IR&D	3126	1922	2000
Subtotal	12245	10318	11064
Out-of-House Research			
Industrial	60	295	480
"In-kind"	2825	3750	4250
Subtotal	2885	4045	4730
Total	19470	19028	20734

Question 27b: Actual and estimated staffing levels.

Answer: These staffing levels include both scientists and technical support personnel. Present scientist staffing at the CRF is 41.

	FY 1987	FY 1988	FY 1989
Facility Staffing			
BES	42.5	44.5	43.5
Conservation	13	15	16
Fossil	8.5	8.5	12
Defense Programs	6	4	4
DoD	4	1	5
NASA	1	1	1
IR&D	8	7.5	7.5
Total	83	81.5	89

Question 27c: Actual and estimated utilization of the facility, and optimal level of utilization of the facility.

Answer:

With sufficient dollars a number of the facilities which the Department runs, including CRF, could be physically operated longer; however, choices have been made according to importance of the research. The Department believes that this is an efficient and effective level of operation. The number of physical hours the facility could be operated would be 7,900 hours.

Question 27d: Level of funding required to achieve the optimal level of utilization of the facility.

Answer: Without further expansion of the CRF facility, the requested funds are sufficient to operate at the physical maximum utilization.

Question 27e: Additional research funding required to support the optimal level of utilization of the facility.

Answer: Without further expansion of the CRF facility, the requested funds are sufficient to operate at the physical maximum utilization.

BASIC ENERGY SCIENCES

Question 28. For FY 1987 - FY 1989, please provide the information requested in a. - e. below for the Stanford Synchrotron Radiation Laboratory at Stanford University.

a. Actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, capital equipment, general plant projects, accelerator improvement projects, and any other funding attributable to the facility. Please indicate the sources of the funds (i.e., Basic Energy Sciences, Nuclear Physics, High Energy Physics, etc.).

Answer:

ALL FUNDS IN $K

	FY 1987	FY 1988	FY 1989
Operations			
Basic Energy Sciences	8,058	8,365	8,530
LLNL	0	150	160
NIH	771	835	900
DOD	281	265	300
	9,110	9,615	9,890
In-House Research			
Basic Energy Sciences	1,800	1,900	1,980
LLNL	30	150	0
NSF	65	67	100
Industry	32	0	0
	1,933	2,117	2,080
Out-of-House Research (Estimated expenditures by the following)			
Government Labs	7,000	5,900	5,900
Industrial Labs	9,000	7,600	7,600
Univ and Other	19,000	16,000	16,000
	35,000	29,500	29,500
Other Operating Expenses			
Stanford University	243	336	368
Capital Equipment			
Basic Energy Sciences	925	1,105	740
Beam Line X (LLNL)	1,026	0	0
Beam Line X-1 (NSF/IBM)	0	100	1,500
IBM	0	200	0
NIH	123	150	150
DOD	29	110	130
	2,103	1,665	2,520

	FY 1987	FY 1988	FY 1989
General Plant Projects			
Basic Energy Sciences	150	270	200
Accelerator Improvement Projects			
Basic Energy Sciences	0	0	0
BES Construction Funding			
SEP Project	1,717	0	0
3 GeV Injector	0	0	0

Question 28b: Actual and estimated staffing levels.

Answer:

Core BES-Funded	59.4	72.7	60.4
Injector R&D (BES)	0	0	0
Injector Proj (BES)	0	25.1	42.0
SEP Project (BES)	6.6	0	0
IBM-Funded	0	1.2	0
LLNL-Funded	12.8	2.7	2.0
IBM/NSF-Funded	0	.9	6.4
NIH-Funded	6.0	6.3	6.7
NSF-Funded	1.3	1.3	1.3
DOD-Funded	.4	.4	.4
Stanford-Funded	4.5	4.9	4.2
	91.0	115.5	123.4

Question 28c: Actual and estimated utilization of the facility, and optimal level of utilization of the facility.

Answer:

With sufficient dollars a number of the facilities which the Department runs, including SSRL, could be physically operated longer; however, choices have been made according to importance of the research. The Department believes that this is an efficient and effective level of operation. The number of physical hours the facility could be operated would be 6,550 hours.

Question 28d: Level of funding required to achieve the optimal level of utilization of the facility.

Answer: In order to achieve physical maximum operations for FY 1989, an additional $2,500K for a total revised DOE operations level of $11,030K is necessary.

Question 28e: Additional research funding required to support the optimal level of utilization of the facility.

Answer: The additional research needed to support the physical maximum of utilization at SSRL is an additional staff member plus research support at a level of $250K for a total in FY 1989 of $2,350K.

Mr. **Bruce**. We are happy to have with us this afternoon, Dr. Robert Sproull, who is Chairman of the Basic Energy Research Advisory Committee. Dr. Sproull, we are happy to have you with us, and look forward to your testimony.

STATEMENT OF DR. ROBERT L. SPROULL, CHAIRMAN, BASIC ENERGY SCIENCES ADVISORY COMMITTEE [BESAC], U.S. DEPARTMENT OF ENERGY

Dr. **Sproull**. Thank you, Mr. Chairman. I think you have a copy of the testimony in front of you. If it's all right with you, I will not read it directly but simply go through it paragraph by paragraph.

Mr. **Bruce**. Oh, please do. Could you just read it to us word by word. [Laughter.]

No, that would be very much appreciated, Dr. Sproull.

Dr. **Sproull**. This committee, as you undoubtedly remember, is in a sense a child of your Committee or your Subcommittee. It has been functioning now for just one year, and it's hard to produce a running commentary on a program as complicated and diverse as the Basic Energy Sciences Program in the Department of Energy.

On the other hand, all of the members of the Committee have had long experience with first the AEC and then its successor, the Department of Energy. So, we didn't exactly start from a standing start. The report that I'm sure you also have—I will not read it either—is our first report of December, 1987. It contains the backup for all the remarks that I will say today. Also, Dr. David Moncton, one of the Committee members is in the audience and he can serve as a truth squad if I diverge from what I am authorized to say.

Before getting into three points that I wish to make here, and just three points, I would also point out that the Director of Energy Research tasked us with a task to comment on the high-temperature superconductors with special reference to magnets for the superconducting supercollider, using that as a touchstone or benchmark as to when this new superconducting technology might become ready to apply.

Dr. Albert Narath, the Vice Chairman of our Committee, led a study and produced a very interesting report, which goes far beyond the necessity of the task in that it outlines the steps that are necessary to be taken to apply these new discoveries in superconductivity to practical programs including magnets for particle physics but including lots of other things as well. And so, I commend that report to your attention too.

The first of the three points that I want to make is that the program is basically sound. We did not find anything in it to be ashamed of or in any way wasting the peoples' money. We found a number of places where it is very thin, but it does not have any gross lack of coverage of the areas of Basic Energy Sciences that are important to the Department of Energy and to the Federal Government.

As part of that we also looked into the balance between continuity of programs and new starts and, in fact, one of the appendices in our report discusses this at length. This also seems to be appropriate. The average lifetime of a program is about 10 years, sometimes a little less. That seems to us to be an appropriate balance between giving a program long enough to accomplish things and, nevertheless, freeing up money to use for new starts for younger people and learn new ideas. If there were more money, of course, you would like to do both. But you have to have a balance between these two.

The second point I wish to make is that there are really three missions for Basic Energy Sciences. They are overlapping and closely related, but they are three distinct missions. The first is the obvious one, underpinning the Department of Energy's own mission. We submit that sooner or later the Department will be blamed for the next energy crisis, and at that time, the complaint will be made that not enough basic energy research was done.

The second mission is that Basic Energy Science shares in many areas, such as materials or chemistry, the basic underpinning of Federal research programs and applied research programs. Basic Energy Sciences does its part along with other agencies, such things as ONR and NSF of underpinning the total Federal program. Now, the situation the last year is rather different and confused but up until at least this last year, DOD and NSF funding had outrun the Department of Energy basic research program. Therefore, this share became more and more difficult for the Basic Energy Sciences group to provide.

The third mission is that BES has created and nourished a unique research user facilities. You commented earlier on how the new budget submission changes and how these are presented. These facilities have been one of the great success stories of the post-World War II period, and your Committee and the Congress ought to take good pride in the fact that these facilities have produced so much good research, so many good people, and have been used as a model around the world for how to do it.

In addition, they are now being especially interestingly applied to providing an arena for industry and university-Government cooperation. It is a marvelous ground where graduate students, postdoctoral and faculty and industrial researchers can all mix in a healthy atmosphere. That's the kind of technology transfer that really makes a great deal of sense and costs very little.

My final point is derived from a comparison of the first two and of the three-part responsibilities with the appropriation history. The usual situation—and it will come as no surprise to you—the responsibilities have expanded faster than the support, especially comparing it with NSF and DOD.

The problem here is like the problem of the deficit. If too little basic research is done in our generation, it will amount to an intergenerational transfer where our children and our grandchildren will suffer because their industry and Government programs will not live on the basic research base that should have been built up.

It would be a sad mistake if basic research suffers in the near term because it has no particular date at which you can be sure to exploit it, in this deficit crisis.

Those are the three points that I wish to make. The report of our deliberations and findings for the first year is far more extensive than this, but I think that these hit the highlights of what we conclude after one year of activity.

I would be happy to answer any questions that you may have.

[The prepared statement of Dr. Sproull and the two BESAC reports follow:]

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

TESTIMONY BY ROBERT L. SPROULL
CHAIRMAN, BASIC ENERGY SCIENCES ADVISORY COMMITTEE

MARCH 23, 1988

Dear Madam Chairman and Members of the Subcommittee:

I am appearing before you today on behalf of the Basic Energy Sciences Advisory Committee (BESAC) of the Department of Energy. As you know, calendar year 1987 was the first year that this committee functioned. All of us had been familiar with some parts of the Basic Energy Sciences (BES) program, but until serving on this committee we had not tried to assess the adequacy and balance of the BES program. For this reason and because of the size and complexity of this necessarily diverse program, we speak with a voice that is not as strong as it will be in later years.

Our report of December 1987 has been made available to you, and so I shall not repeat or even attempt to summarize it here. I should be happy to address any questions you may have about it. Today I should like to make only three points:

1. The Basic Energy Sciences program is basically sound. It consists of high quality research that is relevant to the mission of the Department of Energy. There are no apparent areas that are completely uncovered, but the coverage is very thin in places because of budget limitations. Throughout the program there are promising ideas and approaches that

cannot be exploited within the current budget. Program management is tight and lean and is carried out by some of the most experienced research managers in the Government. There is an appropriate balance between continuity of support and funding of "new starts."

2. It is important to realize that there are three missions for BES, overlapping and closely related. The first is underpinning through basic research the mission of the Department of Energy. When the next crisis in the availability and price of transportable fuels occurs it will become apparent to all that more basic research should have been performed. The uncertainty in the time of harvesting research should not mislead us into underestimating its importance or reducing its support.

   Second, BES shares in many areas, such as materials or chemistry, the underpinning of the total Federal basic and applied research program. BES does its part, along with agencies like ONR and NSF, of supporting the basic research on which Government and industrial technology is based. Although industry, especially a few large companies with good traditions, supports some basic research, no company can afford to do much since the benefits will be shared with its competitors. It is important to note that, unlike some other DOE and some other Federal research support, all of the BES programs are in areas that are applicable, areas where scientific results have great promise of creating new products or of making more efficient and effective the provision of products and services.

Third, BES has created and nourished unique research user facilities for the benefit of the entire Federal, university, and industrial research and development enterprise. These user facilities, such as research reactors and synchrotron light sources, have been one of the great success stories of the last forty years. Some have been closed appropriately (e.g., early research reactors) as more powerful tools became available; but the remarkable effectiveness of sources of light (including ultraviolet and x-ray radiation) produced by accelerating high energy electrons or positrons has required increasing the number of these sources, and it will be some time before any can be retired without substantial damage to research productivity. These user facilities also provide a most effective arena for technology transfer, since people from universities, industry, and Government interact at these facilities in healthy and productive ways. Under the new accounting for FY 1989 the seven existing BES facilities (and the research and development for two new ones) will be a subprogram within the account "Basic Research User Facilities." Our BESAC fully supports the existing and proposed facilities (including the preliminary research and development for the Advanced Neutron Source which evidently remains in the BES budget request) and suggests that your Subcommittee take considerable pride in them.

3. My third and final point is derived from a comparison of the three-part responsibilities just described with the appropriation history. The BES responsibilities have expanded with the need for more basic research to

support an increasingly technological economy and with the expansion of other Federal programs, notably NSF and DoD. But the growth in BES appropriations has not kept pace with the growth in responsibilities. I recognize the pressures on the Administration and the Congress that are produced by the budget deficit and the evident inability of the Congress to control the addition of specific programs, often without additional dollars. But it would be a sad mistake to restrict basic research, an appealing course since the damage would not become immediately apparent. Underfunding basic research will result in the same kind of intergenerational transfer as the budget deficit, since our children and grandchildren will suffer. In this light, the DOE 1989 Budget Request for BES (and BES-related facilities under BRUF) is far too modest.

Thank you for your attention. I should be happy to answer questions about this brief testimony, about our report, or about the functioning of the BESAC.

DOE/ER-0359

A REPORT OF THE BASIC ENERGY
SCIENCES ADVISORY COMMITTEE

1987 REVIEW OF THE BASIC ENERGY SCIENCES PROGRAM OF THE DEPARTMENT OF ENERGY

December 1987

U.S. Department of Energy
Office of Energy Research
Washington, D.C. 20545

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Membership of the Committee

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Prof. Mark S. Wrighton, Professor, Department of Chemistry
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I. Introduction

We report after an extremely active year of meetings, briefings, laboratory visits, and consultation with Department of Energy (DOE) staff. Furthermore, all the members of the basic Energy Sciences Advisory Committee (BESAC) have been close observers of the Basic Energy Sciences (BES) program for decades and most have been active participants. Even with such activity and experience, however, the BES program is so rich and varied that we need more time to cover adequately the issues and opportunities that the program presents and to make truly incisive recommendations. Reports in future years can therefore be expected to speak with a stronger voice.

In order to attack our study of the quality, adequacy, balance, and management of the BES program we found it necessary to set up six subcommittees, with most members of BESAC serving on more than one of them. The reports of the six are appended as Appendices A-F. Although in Section II below we extract some key points from these reports, the real meat of our report is in these appendices, and we strongly recommend attention to them.

In April, 1987, Dr. Trivelpiece tasked us to organize an expert panel to study the recent discoveries of high temperature superconductors. The focus of this study was to be the materials development and time required to harvest the new discoveries for the lattice of a superconducting supercollider. The panel was set up under our Vice Chairperson, Dr. Albert Narath, and among its experts were other members of BESAC (Drs. Flynn, Fradin, and Moncton). The report of the panel will be submitted separately at about the same time as this report.

In section III we address some "global" questions and issues in energy research and in BES, points that cannot be decomposed into divisions and consigned to subcommittees. Nevertheless, the wisdom of this section is derived from the work of the subcommittees.

We register here our most basic global conclusion: the funding of BES has not expanded enough to deal adequately with the needs, and certainly not the opportunities, facing the nation and the DOE. The inadequacy of funding is most sharply revealed by contrast with the NSF's significant increases. Although BES serves the DOE's mission, its basic research is very similar to NSF's. Furthermore, BES supports expensive National research facilities heavily used by grantees of NSF and other Federal agencies.

As we worked in the spring of 1987 we identified two issues that were urgent as well as important: the interruption of the vital service to research by the High Flux Isotope Reactor and the opportunities presented for research in high T_c superconductors. We reported briefly our recommendations on these issues in a letter of 29 April to Dr. Decker; that letter and his reply are Appendix G.

Finally, for the record we have appended the letters and charter that created BESAC as Appendix K.

II. Content of the Program

1. National User Facilities

One of the great success stories of science and technology in the post-World War II period has been the DOE's National User Facilities (detailed report in Appendix A). Focusing money and talent into the design, construction, and intense application of these sophisticated facilities has proved to be so effective and efficient that it is now hard to imagine how science and technology in the U.S. could have developed without them. Our subcommittee has found these facilities to be of excellent quality and appropriately managed for the benefit of those users with the most promising ideas and plans for the most important experiments, both for the benefit of BES and other DOE programs and for the benefit of other Federal programs, notably NSF and NIH. Although most are at National Laboratories, users from universities and industry get fair and generous treatment, and the facilities provide an arena for healthy interactions among these communities and for technology transfer. Industrial users of these facilities contribute resources and talent that provide research in support of DOE and the other Federal agency missions.

The High Flux Isotope Reactor should be restarted as soon as safely possible. BESAC endorses the DOE's budget request for the construction of the Advanced Light Source, the Advanced Photon Source, and the Advanced Neutron Source, but not at the expense of other BES science and its mission. These facilities will serve National needs and the BES program should not be milked to create and operate them.

We are unable to provide a recommendation as to whether the costs of facility operation should be identified in a separate line item; there are advantages and disadvantages to that method and to the present system. We anticipate that we will make a definite recommendation next year.

However budgeted, there is high leverage to funding these facilities at a rate such that the output of science is limited only by the imagination of the scientists and the capacity of the machines, not by the number of hours per year restricted by an inadequate budget.

Funds should be provided annually to maintain, upgrade, and restore these facilities. In addition, major emergencies will always recur in ambitious, state-of-the-art facilities, but since these are unpredictable, money cannot readily be set aside (and possibly not used) to get a facility back into operation (See Section III, 7).

2. Materials science

Materials Science (Appendix B) is central to the mission of DOE, and the program in BES is outstanding in its health and vitality and in its responsiveness to National needs. The program is well managed and coordinated with the similar programs of other Federal agencies. An illustration of the flexibility of DOE management and the effectiveness of local management at the laboratory bench level occurred this year when many scientists and engineers quickly re-oriented their research to exploit the superconductivity discoveries.

Less-than-cost-of-living increases in budgets over the past five years have narrowed the coverage of materials opportunities, and funding of programmatic research should be increased in real terms. Advanced synthesis and processing, especially of the newer superconducting materials, should be featured. The major user facilities are especially important to materials research and (as noted above) their development and operation should be fully funded.

Technology transfer is being effectively executed in materials, but there is a danger that some of the BES Materials Science activities may suffer by being too close to proprietary information, with the attendant restriction on publication. The program must be nourished and defended as a basic, long-term activity. Technology development and transfer can best be enhanced by expanding the training of Ph.D. students and postdoctoral fellows in environments where industry participates and by visiting scientist and visiting faculty programs.

3. Chemical Sciences, Biological Energy Research, and Carbon Dioxide Research

Chemical Sciences (see Appendix C for the report on it and on biology and carbon dioxide) is a large and effective division, with about two-thirds of its expenditures in the National Laboratories. In the face of an expanding role of chemical science in energy and in the country generally, the research budget has not grown in real terms. Management has responded appropriately to ERAB and other National studies in adjusting priorities within a constant budget.

The subcommittee detected a growing tension in Chemical Sciences between fundings for research budgets and major facility operations. The Chemical Sciences Division probably needs to devote more attention to understanding and keeping abreast of current industrial programs in areas such as catalysis where both the Division and industry are active. In some other areas, the Division supports the entire National program (for example, transuranium isotopes and the structural characterization of coal), and this creates special responsibilities. The Chemical Sciences Division is widely viewed as having the premier program in photoconversion research.

Biological Sciences is new and much smaller (when one removes Congressionally mandated programs and construction), but it is already conducting important research such as the structural characterization of complex carbohydrates involved in energy conversion. Again, the program managers should become more aware of publicly available information about industrial developments in this fast moving industry. We recommend that Biological Energy Research remain in BES and not be moved to the Office of Health and Environment; we deal here with the basic science related to energy production, not the science related to the consequences of energy production. The small Carbon Dioxide Research program is also appropriately part of BES. Serious and broad-based science is required to determine the consequences of CO_2 production. The selection of research needs to be accomplished with strong participation by outstanding research scientists. The explosive expansion of computing power presents a special opportunity to compare global models with the output of a vigorous experimental program.

4. Engineering and Geoscience

The small BES programs in engineering and geoscience (Appendix D) must be considered in relation to the much larger (nearly a factor of ten) programs in these fields in other parts of DOE. We question that the present size ratio constitutes an appropriate balance.

Engineering research in BES employs some of the best engineering scientists in the country in a strong but relatively unfocused program that has placed emphasis on fundamental fluid mechanics, related thermal and chemical sciences and nonlinear dynamics. The severe resource limitations prohibit across-the-board coverage of these areas. There is even more limited coverage of other energy-related engineering sciences in solid, structural, and fracture mechanics and in systems, instrumentation, sensors, and control. If adequate funding cannot be secured for the engineering research program, it will be necessary to develop a much more coherent basis for the difficult decisions on which, among a host of promising areas, should in fact be selected over others and, also, the extent to which a small number of areas of sharp focus (as opposed to broad overall coverage) is desirable. In addition to the two-phase flows at high Reynolds numbers (important for such topics as heat transfer loops with condensation, slurry pipelines, materials processing, and combustion with droplets or particulates) there is also great DOE interest in the complex subsurface flow problems at low Reynolds number important for reservoir engineering, resource extraction, waste isolation, and the like; close coordination with fluid transport and porous media studies in geosciences should be pursued to provide rational overall coverage of these areas. There is relatively little materials processing engineering in the BES program (or in any other Federal program), and that area is increasingly important to DOE.

The geosciences program probably has too little attention given to fossil energy. We agree with the ERAB recommendation ("Guidelines for DOE Long Term Civilian Research and Development," DOE/S-0046, December, 1985, p.3) that one of the primary National objectives must be to "reduce U.S. long term dependence on foreign oil." Indeed, we fully expect another "oil crisis" in a few years, and the popular cry will be addressed to DOE: "You should have prevented this." Thus it is easy also to agree with the thrust of the recent ERAB report ("Geoscience Research for Energy Security," DOE/S-0056, February, 1987) for expanded work on oil and gas. We do urge, however, that the short-term work called for in that report be complemented by longer-term geoscience to increase our understanding of the locating and production of liquid fossil fuels. There is still much relevant knowledge to be learned about the behavior of oil in the ground, and acquisition of this knowledge will require longer-term research, preferably in conjunction with universities.

The Continental Scientific Drilling Program is an important National effort, but it absorbs a large part of the BES geoscience budget and support for it appears to have recently come at the expense of decreases in geoscience university research, which seems to us to be unfortunate. Also, the concentration on "thermal regime" areas does not underpin the main need, namely more understanding of oil and gas opportunities.

To convey our sense of the importance and urgency of geoscience research, we have included in Appendix D a paper by one of our members, Prof. Travers.

5. Applied Mathematical Sciences Research

We have not had the expertise within the BESAC to examine this program (Appendix E) in detail; we expect to rectify that deficiency next year. Meanwhile, however, we question the removal of Applied Mathematics from close coordination with the physical sciences programs within BES. Also we recommend a review by physical scientists and computer scientists of the large Florida State University effort, which seems currently to be of use primarily to the High Energy Physics program. If the review reveals substantial participation in BES research of quality and relevance comparable to other BES programs, the Florida State program should be given a continuing budget category.

6. Advanced Energy Projects Research

We endorse the concept of this program (Appendix F) of high-risk, potentially high-payoff projects that have scientific merit but are too unconventional to attract funding in routine ways. The sensible rules BES has created for this program permit funding for only a limited time, and some successes of getting other agencies to fund continuances have already been registered. Our subcommittee has reviewed a sampling of proposals and found them to offer a generally high level of timely, forward-looking and energy-relevant science.

In addition to this "core" program, AEP has a large, long-term project, the Heavy Ion Fusion Accelerator Research. If this program is to progress it needs a massive injection of money, an additional $26 million over four years. The work itself is of excellent quality performed by people who are obviously experts. A heavy ion accelerator may well be the most promising driver for a full-scale inertial confinement fusion energy plant. But such a plant is a long way in the future, and only possible (if at all) after much modeling and experimentation of the coupling of energy to fuel pellets and of their compression. HIFAR does not claim to advance that time.

We are not in position to evaluate the timing and interaction of the various DOE programs in inertial confinement fusion. We question whether programs with definite delivery times have any place in BES. With all the more urgent requirements on BES, the expansion of HIFAR should take a low priority within BES. We understand that this probably means the program will be phased out unless it is reviewed positively in the context of the total DOE fusion effort and funded outside the BES budget.

III. Global Issues

Difficult as it is to comment usefully and confidently on individual parts of the BES program after a one-year study, it is even more difficult to contribute to the resolution of issues that transcend the boundaries of these parts and concern the program as a whole. We make a start this year and hope that the following comments will serve at least as a check-list of concerns for BESAC in future years.

1. Coordination with Other Federal Programs

We have persistently challenged the BES management about their knowledge of and relations with other Federal research programs. We are wholly satisfied that the BES program complements and does not duplicate programs in NSF, DOD, Department of Interior, Department of Commerce, NIH, NASA, and other agencies. BES naturally has especially close relations with NSF, and the partition of interests is handled expertly with special attention to the DOE mission. The new interest in superconductors suggests that we recall how for many years the U.S. Navy carried the principal role of research on the use of superconductors in rotating machinery (motors, generators, alternators) even though success would have important consequences for energy conversion by electric utilities. Through BES the DOE provided basic research underpinning for the Navy program, and through the Navy's industrial contractors and other branches of DOE, the DOE was in an excellent position to harvest this work for national energy needs.

Congress and the OMB are traditionally apprehensive about possible duplication in programs in different agencies (e.g., NSF and BES) that carry the same titles (e.g., "materials science"). The coordination in the case of BES is continuous and effective in Washington. In addition, however, it is worth noting that duplication is effectively prevented at the laboratory-bench level: No scientist or engineer knowingly duplicates others' work; it would waste precious time in the only life he has, make him look silly to his colleagues, and prevent his successful competition for renewed Federal support.

2. Relations with Industry

The ultimate consumer of most of BES-supported work is American industry (exceptions are DOE's Defense Programs and a few others). Thus it is important that BES not only be nonduplicative with industry but also that it supports mechanisms to feed research results into the creation of goods and services for consumers. We have noted above (II3) that some additional effort may be needed to keep abreast of industrial research, which is not an easy task in fast-moving or proprietary areas. We have also noted successful technology transfer activities, especially in connection with user facilities. The Interactions are most impressive at installations like a synchrotron light source or a reactor for neutron diffraction and scattering; graduate students, postdoctoral fellows, faculty, and industrial scientists and engineers acquire knowledge of each other's approaches and respect for one another.

The boundary between what the Federal Government should support and what companies should do for themselves is always a subject for comment or even controversy. The BES programs are squarely within the area that we (and we think almost all others) believe is the role of the Government. An industrial company can provide capital for future production only if it can produce an internal rate of return of the order of 20% (which provides a dividend yield to shareholders of about one-fourth of this 20%). Research with payoffs ten or twenty years in the future cannot therefore generally be supported, even if it were guaranteed to produce marketable results. Furthermore, much research would benefit the company's competitors as much as itself. The Government role is thus for longer term research with payoffs for more than one company, and the BES programs are soundly within this pattern.

3. Adequacy

We can confidently predict that when the "energy crisis" recurs the BES programs will be perceived to have been insufficient in quantity. More money could be effectively spent in every part of the program; all research areas are resource-limited, not idea-limited. Perhaps the program is as large as we can reasonably expect, given the overall Federal budget pressures, but we have noted above substantial underfunding in some areas. We must leave to our betters in Congress and the Executive Branch whether the total Federal research support and BES' fraction of it are sufficient to carry the U.S. confidently into the next century (we doubt it).

4. Future Program Needs

We have identified above some needs and are pleased that BES management is already aware of them. We have noted above the urgency and importance of returning HFIR to operation and replacing it as soon as possible by the more capable ANS. We have urged immediate attention to a major thrust in superconductors. We have endorsed the new synchrotron light sources, which are badly needed since present facilities are overloaded and since there are substantial research opportunities with more powerful machines. We have also noted that more work is needed in engineering, in materials synthesis and processing, and in understanding the properties and processes of oil in the ground.

The greatest need is for additional dollars; the mission of BES has increased in scope, but the dollars have not been added. We propose to study this need in more detail next year.

5. Balance Among Fields

It is virtually impossible for a group like ours to comment usefully on the balance among fields (see Appendix H for the budget breakdown). Each of us finds his own field to be underfunded; if the reader finds that grimly amusing, perhaps he would consider how forbidding the world would be if the reverse were true. The BES program in conjunction with other Federal programs, provides sensibly balanced, although insufficient, support of the longer-term science and engineering appropriate to the DOE mission.

6. Balance Between Facilities and Research Projects

This question was raised (but not answered) in the National Users Facilities report (Appendix A, p. 1). The seven major facilities require for their operation (excluding construction and the research carried on at them) about 17% of the BES annual expenditures. Although this amount is an inexorable subtraction from available resources year after year, it does not seem excessive to us. Clearly BES has steered an appropriate middle course between under-utilized, expensive facilities and inefficient research through lack of central facilities.

The present plight of HFIR alerts us again to a recurring problem: User facilities will always be highly complex, sophisticated apparatus at the leading edge of technology, and therefore they will frequently need repairs and modifications. Is it possible to invent a mechanism, within a Government that is allergic to contingency funds, for dealing with these emergencies without forcing research to suffer?

7. Balance Between National Laboratories and Universities

This touchy subject was addressed only slightly and obliquely by BESAC. Each group respects the other, but in budget pinches the tension can run high. Both have creative people and each has its special attributes: National Laboratories provide a continuity of experienced scientists, engineers, and technicians and create and keep up to date most of the National User Facilities for the benefit of all; universities provide the training of a new generation of scientists and lower costs per person-year. The current funding ratio of research funds (excluding capital and facilities operations) is about 63% in National Laboratories, 34% in universities (the remaining 3% in industry, NBS, etc.). There is nothing obviously wrong in these percentages, which have been nearly constant since FY 1985. (The number of projects in universities has grown with respect to the number in National Laboratories, but the average size in constant dollars has decreased; see Appendix I, p. 3). Colocation of BES programs with other DOE programs at National Laboratories is important to the feeding-in of BES work to other DOE programs.

8. Turnover of Research Projects

Our BESAC was concerned with the degree to which programs were "frozen" and the degree to which BES responded to new opportunities and identified new promising people. Appendix I presents the BES response to our queries and indicates that the average duration of projects is now 8.4 years for National Laboratories and 8.1 years for universities. This interval has declined 20-30% in the last ten years, which indicates a continuing refreshening of the research content of the BES program. The BESAC supports the general pattern of stable but not stagnant funding for basic research that this analysis presents.

9. Organization

Appendix J summarizes the current organization of the Office of BES. We have not seriously analyzed possible alternate organizations; this one seems sound and is working well, but the small number of staff is spread thinly. Elsewhere in this report we have commented that the biology program should stay within BES, and we have revealed our ambivalence about the possible separation of facilities into a budget line item, which would presumably call for a separate manager of that line.

10. BESAC Composition

A computer scientist or applied mathematician should be added to BESAC. Additional people from industry would be very helpful. Possibly one or two additional people from the laboratory bench in universities would be wise. We appreciate that recruiting in these last two categories may be difficult since those populations may not have sufficient incentives to donate the substantial amount of time that BESAC requires.

Appendix A

Subcommittee on User Facilities
Basic Energy Sciences Advisory Committee

C. P. Flynn
F. Y. Fradin
D. C. Hoffman
D. E. Moncton
J. M. Rowe (Chair)

In recent years, several National User Facilities have been developed in the U.S.A. to provide shared access to central, specialized experimental capabilities for researchers from a broad range of disciplines. The Office of Basic Energy Sciences operates approximately 75% of these, with the remainder supported by the Department of Commerce and the National Science Foundation. The present report is concerned only with the DOE/BES facilities. These facilities are a major national resource, providing individual researchers with unique opportunities for research with advanced techniques. The cost of building and operating these facilities is such that only a limited number of centers can be supported, and researchers must travel to these centers for their research. However, it should be emphasized that these facilities are not analogous to High Energy Physics machines, in which a small number of experiments are performed by large teams of scientists. Rather, they provide many types of instruments at which small groups of individual researchers perform measurements of many types on equipment provided jointly by the facility and the users. Thus, they represent the shared use of specialized equipment for a broad and diverse group of researchers, providing capabilities and opportunities that none of the groups could afford on their own. Although the cost of operating these facilities is, for mainly historical reasons, allocated to one or two divisions within OBES, the Users are drawn from many disciplines, and the facilities serve the research needs of a much broader community than might be apparent from the organizational structure. The User facilities are divided into two categories for the purpose of discussion - Major and Minor. The division is on the basis of operating budgets, with the break point at approximately $2M/year. A list of the facilities included is given in Attachment A (note that currently planned as well as operating facilities are listed and included).

The subcommittee recognizes that there are a number of global issues relating to the balance between major facility-based research and other research areas that should be addressed by BESAC. These relate primarily to the following: The large capital cost and operating expense of major facilities relative to other research needs within the areas served by the facilities; the balance of National Laboratory activities resulting from the incorporation of successive facilities; and the effect of facility commitments on the long-range deployment of scientists in the U S.A. These issues lie within the scope of the full BESAC, and are not addressed within this subcommittee report, which is restricted to recommendations related to the best development and use of the facilities themselves.

For this year's report, the subcommittee has concentrated on Major Facilities, and has done little examination of the smaller ones. This is not meant to slight the importance of the latter, but is a reflection of the limits of time. It is clear from both the limited observation of this subcommittee and the presentations made to the other subcommittees (especially the Materials Science subcommittee) that they play a major role in the science programs of BES and of the nation. It should also be noted that facilities do not run forever, and that many facilities have been shut down when they have outlived their utility. For example, the Ames reactor, the CP-5 reactor at Argonne and the ORR at Oak Ridge have all been shut down in the past few years (as well as other earlier reactors), and it is anticipated that the HFIR will shut down when the Advanced Reactor comes on line.

It is difficult to separate out a small number of scientific and technical highlights from the large body of excellent research done at major facilities. However, the brief list given below should give some indication of the breadth, diversity and importance of major facility research.

- Researchers from Stanford Synchrotron Radiation Laboratory, Stanford University, Lawrence Berkeley Laboratory and Brookhaven National Laboratory have developed a noninvasive technique for angiography using synchrotron radiation. This technique has been used on human patients, and offers the possibility of safe diagnostic detection of the early stages of heart disease.

- Researchers from Brookhaven National Laboratory, along with many collaborators from other government laboratories, universities and industries, have used neutron scattering at the HFBR to show the existence and importance of magnetic interactions in the new high T_c superconducting materials. This information is critical to theoretical understanding of these important new materials.

- Researchers from Argonne National Laboratory have used neutron diffraction techniques at the IPNS to correlate structural details of the new high T_c superconductors with superconducting properties on a continuing basis, thus providing information critical to better materials preparation on a time scale short enough to allow its incorporation into new compounds.

- Researchers from Sandia National Laboratory have used the special capabilities of the CRF to develop a new technique for removal of nitrogen oxides from exhaust streams, and demonstrated its feasibility on diesel engines. This technology is in the process of being transferred to the private sector.

- Researchers from IBM have used the facilities at NSLS to develop X-ray lithography for use in the production of supercomputer chips in the 1990s and beyond. This program now leads a world-wide initiative to bring research and development efforts into manufacturing. X-ray lithography will comprise the first large scale technological application of synchrotron radiation.

- Scientists from Exxon Research and Engineering Company have developed various diffraction and imaging methods with synchrotron radiation to study the structures of the complex materials used in energy processes. A particularly noteworthy effort at NSLS has led to the development of three-dimensional X-ray microtomography methods capable of one cubic micron spatial resolution.

- o Researchers from LLNL and LBL have utilized the unique transuranium elements produced at HFIR and TPP to produce new, relatively long-lived isotopes of element 103 (Lr) and also to perform the first aqueous chemistry on element 105.

We have derived information on the operation and use of the major facilities from primarily three sources:

1. Requests were made to the manager of each major facility to provide us with information on costs, number and affiliation of users, on experimental equipment of users, on experimental equipment available, on papers published and on other aspects of facility operation. These data have been assembled and cross-referenced, and some salient results are presented in graphical form in Attachment B. Further information and the raw data are available from the chairman.

2. Several committees have performed in-depth reviews of major facilities from several aspects, and have produced reports of their reviews. A partial list of such reports is given in Attachment C.

3. A meeting was held at Argonne National Laboratory on August 5 at which a representative of each major facility made a short presentation and answered questions from the Committee members present. The agenda for this meeting is reproduced in Attachment D.

As a result of this activity (which should not in any sense be considered a comprehensive review of any individual facility), the subcommittee has arrived at several general findings, identified some major issues, and suggests some recommendations for the full committee to consider.

Findings

1. The Department of Energy has the major national role in providing centralized facilities for the benefit of all researchers in the U.S. This role has developed as a result of its history, deriving from the operation of reactors under the Atomic Energy Commission. The operation of these facilities must be placed in a National context, as they serve the needs of many different research communities. Although many non-DOE researchers use the facilities, their research often supports the DOE mission, and provides extra research leverage for direct DOE expenditures.

2. The facilities provide unique research opportunities for individual researchers, and promote efficient use of scarce resources. They are not "big science" oriented, but rather provide a sophisticated subset of the many techniques utilized for the study of individual research problems. They also provide enhanced opportunities for government-industry-university cooperation as a result of the many different research teams that perform experiments at them.

3. Although the facilities are operated primarily for the benefit of the users, not the laboratories at which they are situated, there are many benefits which accrue to the laboratories from the continuous flow of

diverse scientists and the time allotted to DOE programmatic research. Operation as user facilities is a relatively recent development, and the newer facilities such as the synchrotron radiation sources and pulsed neutron sources which were organized with this role from the beginning, are currently more effective in serving users. The user mode of operating is essential for the proper utilization of limited and expensive resources.

4. The facilities are, in general, fulfilling their role to provide top quality research opportunities. They are in general well-operated, and the quality of the science being produced is excellent. The user aspects of operation are being explored in depth by separate committees, one of which (on neutron sources) has submitted a draft report.

5. The OBES is implementing the recommendations of the recent committees that have addressed major facilities issues and needs in an orderly fashion at a pace consistent with budget constraints, but substantially slower than would be scientifically optimal.

Issues and Opportunities

The subcommittee has identified a series of issues and opportunities related to the operation and construction of major facilities. These are listed below under three broad categories, which are not in priority order.

1. Operation of Existing Facilities

- The High Flux Isotope Reactor at Oak Ride National Laboratory is shut down as a result of problems with the pressure vessel, removing a vital part of the neutron scattering capability, and the entire transuranium element production capacity in the U.S.A. from service.

- The large number of users at the facilities has resulted in some strain on user services, especially at NSLS (e.g., office and laboratory space, housing). Some of this will be alleviated by the completion of NSLS Phase II, and BNL has plans to improve the housing supply. This will, however, continue to be a problem at all of the major facilities as the number of users increases.

- Some facilities are not operating in an optimum fashion as a result of funding limitations (HFBR, IPNS, SSRL). In each of these cases, relatively small incremental funding could provide large percentage increases in operating time, thereby making better use of large capital investments. In many cases, additional funding for equipment development and upgrades would also pay large dividends in efficient utilization of existing facilities (e.g., HFBR). At SSRL, an agreement with High Energy Physics to allow full dedicated use of SPEAR for synchrotron research would lead to much more effective use of available resources.

2. Construction of New Facilities

The construction of new facilities (Advanced Light Source, Advanced Photon Source, Advanced Neutron Source) with dramatically increased flux and brilliance represents a great opportunity. Not only are the current facilities over-subscribed and unable to meet the demonstrated need, but entirely new research possibilities will be created by the greatly increased performance of the new sources. While OBES has recognized this opportunity and is moving to provide the necessary resources, the current funding profile is not optimal from a scientific viewpoint.

3. Budget

The Energy Research Advisory Board, among others, has recommended changes in the organization of OBES budgets, so that Facilities Operation will appear as a separate line item.

Recommendations

1. The full BESAC has forwarded a recommendation to OBES for the earliest possible restart of the HFIR, consistent with safety considerations. The subcommittee strongly endorses this recommendation.

2. The subcommittee recommends continued and accelerated pursuit of the construction of new facilities (ALS, APS, ANS) as was recommended by the DOE in its 1987 budget, by the Energy Research Advisory Board, and the report on Major Facilities for Materials Research and Related Disciplines. However, we emphasize that this must not be done at the expense of other OBES scientific programs. This is an issue of National scope in which OBES has the lead role, and we urge the Department of Energy, other Federal agencies and private institutions, all of which benefit from the major user facilities, to support DOE in obtaining the necessary funding increases to allow OBES to pursue a more optimum development schedule. The estimated operating costs of these new facilities are given in Table 1.

3. The subcommittee has not agreed on the issue of a separate line item for Facility Operation. Therefore, we reproduce below the arguments for and against this change, for the consideration of the full Committee.

For: At present, facility operation is spread over divisions in a manner that does not reflect actual usage of the facilities. This results in the perception that one program is paying for facilities for unrelated research, and in view of the constant pressure on budgets, causes strong concern. The new arrangement would be more logical and understandable to the community at large, and would clearly show where money was going. It would allow for a clear division of research and facility funds, and would allow the case for facility operation to be presented separately in budget justifications, thereby enhancing long-range planning for facility operation when new facilities come on line.

Against: Although the present arrangement is somewhat ad hoc, facility operations are clearly identified in all budget documents. Decisions are made by OBES scientific program managers, so that tradeoffs can be made by those most affected. The current system provides great flexibility, and helps to insulate such decisions from outside pressures. Since the present system works, it should not be changed.

4. Existing and planned facilities should be adequately funded to ensure full and effective operation. This can provide substantial increases in utilization for a small incremental cost. Some examples are given in Table 2.

5. The subcommittee is willing to review any proposals for substantial (>$5M) projects or changes in operating costs if requested to do so by OBES. The subcommittee report on such items would then be reviewed by the full BESAC.

Table 1. Projected operating costs for proposed and approved new major facilities. Numbers in parentheses are the fiscal year dollars used for the estimates.

Advanced Photon Source	$44M (FY89)
Advanced Neutron Source*	$25M (FY89)
Advanced Light Source	$18.5M (FY93)

*Of this cost, approximately $17M will be derived from the shutdown of HFIR.

Table 2. Examples of increased efficiency of use of existing major facilities that could be obtained by incremental funding shown. Data derived from Volume IV of the FY87 Hearings of the Committee on Science and Technology, U.S. House of Representatives, pp 81-90.

Facility	BES Operating K$	Increment for Full Use	% $ Increase	% Efficiency Increase
IPNS	5,835	1,500	26	62
HFBR	9,000	1,500	17	16
SSRL	9,741	5,500	56	100

Attachment 1

MAJOR FACILITIES

Advanced Photon Source (R&D) Intense Pulsed Neutron Source	Argonne National LAboratory
National Synchrotron Light Source High Flux Beam Reactor	Brookhaven National Laboratory
Advanced Light Source (FY88 Const)	Lawrence Berkeley Laboratory
Los Alamos Neutron Scattering CEnter	Los Alamos National Laboratory
High Flux Isotope Reactor Advanced Neutron Source (R&D)	Oak Ridge National Laboratory
Stanford Synchrotron Research Laboratory	Stanford University
Combustion Research Facility	Sandia National Laboratories, Livermore

MINOR FACILITIES

Electron Miscroscopy Center for Materials Research	Argonne National Laboratory
Shared Research Equipment Program	Oak Ridge National Laboratory
Center for Microanalysis of Materials	University of Illinois
Materials Preparation Center	Ames Laboratory
National Center for Electron Microscopy	Lawrence Berkeley laboratory
Low Temperature Neutron Irradiation Facility	Oak Ridge National Laboratory

Attachment 2

Selected Data on Major DOE/BES User Facilities

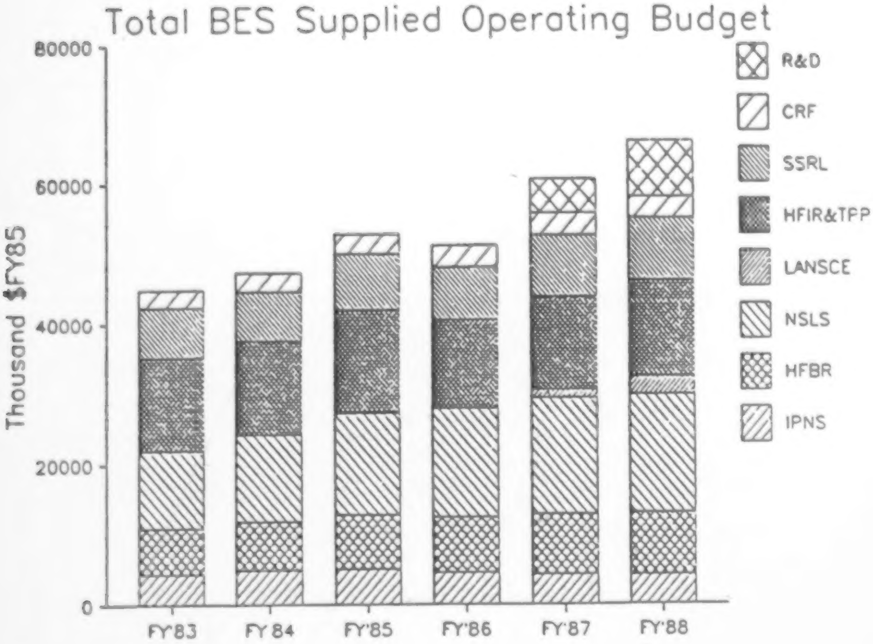

Figure 1. The numbers shown include only BES funding for major facilities - they do not represent total operating budgets, although in most cases, DOE/BES supplies the majority of funding. Note that the HFIR & TPP budget includes the Transuranium Processing Plant costs, while Figures 2 and 3 on users and papers do not include data from the transuranium element program.

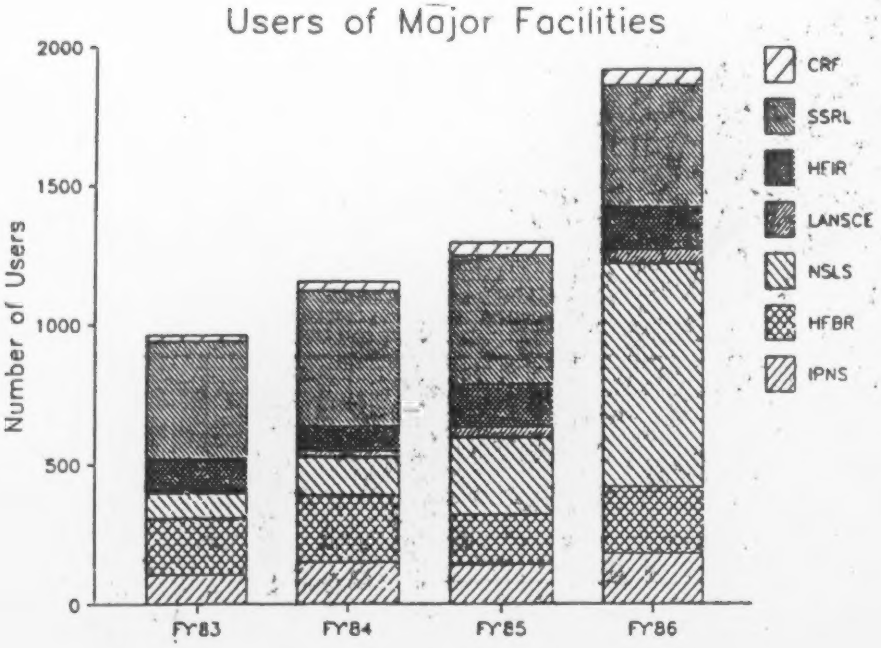

Figure 2. Total number of users of major DOE/BES major facilities. A user is defined as a person who actually shows up at the facility to do an experiment. Multiple visits by one person are counted as one user. Note that for HFIR, this does not include users of transuranium elements.

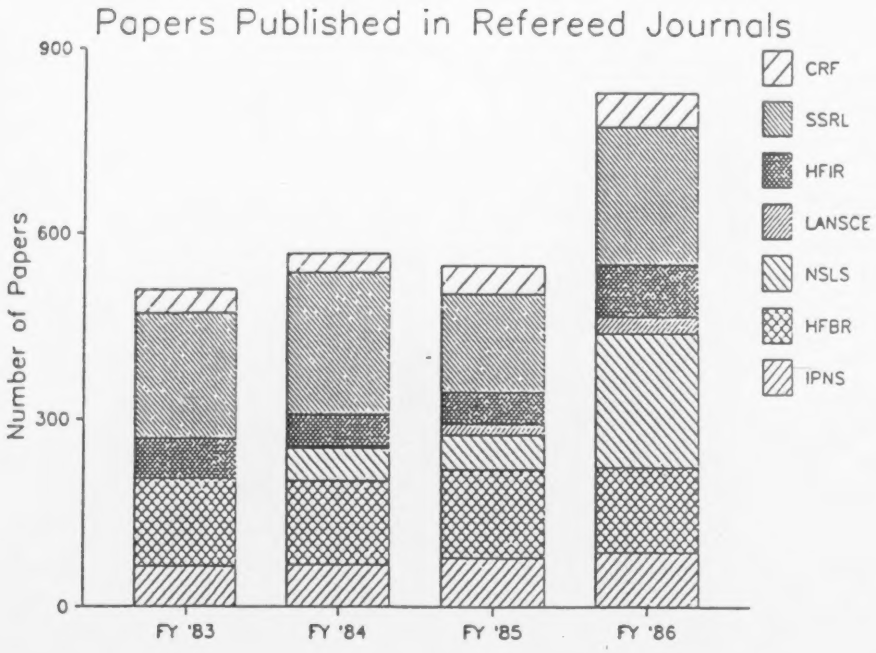

Figure 3. Total number of papers published in refereed journals as a result of research done at major DOE/BES major facilities. The number of papers shown for HFIR does not include those resulting from the transuranium element program.

Attachment 3

Selected Bibliography

Draft of Report on Neutron Scattering Facilities Supported by the Department of Energy, P. Pincus, Chairman

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Current Status of Facilities Dedicated to the Production of Synchrotron Radiation, National Academy Press, Washington, DC (1983)

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Review of the National Research Council Report Major Facilities for Materials Research and Related Disciplines, Energy Research Advisory Board, DOE/S-0037 (1985)

Guidelines for DOE Long Term Civilian Research and Development, Energy Research Advisory Board, DOE/S-0046 (1985)

Attachment 4

Agenda for Meeting at Argonne National Laboratory, August 5, 1987

8:00 AM	Introductory Remarks, Mike Rowe
8:05	Overview of Major Facilities, Iran Thomas, BES
9:00	Intense Pulsed Neutron Source, Bruce Brown, ANL
9:45	High Flux Beam Reactor, Larry Passel, BNL
10:30	Los Alamos Neutron Scattering Center, Roger Pynn, LANL
11:15	High Flux Isotope Reactor, Ralph Moon, ORNL
12:00	Advanced Neutron Source, Colin West, ORNL
12:30	Working Lunch, Report on User Aspects of Neutron Facilities
1:00	Advanced Photon Source, Dave Moncton, ANL
2:00	Advanced Light Source, Jay Marx, LBL
3:00	National Synchrotron Light Source, Michael Knotek, BNL
4:00	Stanford Synchrotron Radiation Laboratory, Art Bienenstock, Stanford
5:00	Combustion Research Facility, Peter Mattern, Sandia

Appendix B

Subcommittee on Materials Sciences
Basic Energy Sciences Advisory Committee

C. Flynn
F. Y. Fradin (Chair)
D. E. Moncton
J. R. Rice
J. M. Rowe
L. T. Silver

Introduction

The Materials Sciences Subcommittee of BESAC met at Argonne National Laboratory on August 6 and 7, 1987. This meeting served as an opportunity to review the major programmatic thrusts of the OBES-DMS program. Presentations were made by Ames, Argonne, Brookhaven, Lawrence Berkeley, Los Alamos, Oak Ridge, and Sandia National Laboratories, as well as the University of Illinois (Urbana-Champaign) Materials Research Laboratory. The programs in these laboratories make up greater than 50% of the base program of BES-DMS, excluding major facilities. Thus, the Subcommittee was able to gain perspective on the technical program and various other issues that the laboratory managers were asked to address, including high priority program opportunities for future attention and the role of major facilities and collaborative user facilities in programmatic research. The Subcommittee has not yet reviewed the multifaceted programs supported by BES-DMS at the universities.

The BES-DMS program is a major component of the Nation's fundamental research on materials. Together with programs of roughly equivalent size funded by the NSF and the DOD, it underpins much of the future materials technology development in the U.S. Furthermore, through co-location with technology programs at the National Laboratories and via numerous DOE contractors meetings, the OBES-DMS program is responsive to DOE's missions. (A tabulation of funding history is attached at the end of the report.)

Findings

The Subcommittee has found through presentations at the August 6-7 meeting and from various other information sources the following facts:

1. The technical vitality and health of the OBES-DMS program is outstanding. Major components of the program are resident both at the National Laboratories and at Universities.

2. A large degree of flexibility is a feature of the program, which allows for rapid progress to be made in new areas by program redirection at the laboratories and universities. The most recent example is the outstanding contributions to the new field of High Temperature Superconductors. Much of the redirection came from related programs on low-temperature superconductors. However, additional experts in the base program in ceramics, thin films etc. also have focused their efforts on this new field. Such reprogramming was driven by the excitement of the scientific

opportunities and was not mandated by BES.

3. Program leadership at the Laboratories is very good. This has been made apparent by solidly organized, significant research efforts in numerous important materials areas.

4. Less than cost of living increases over the past 3 years in the nonfacilities part of the Laboratory operating budgets has generally led to a shrinkage and consolidation of programs resulting in narrower coverage in the broad spectrum of materials research opportunities.

5. The major user facilities and collaborative user facilities are key factors in the scientific progress of an important fraction of the program. This has been especially apparent for neutron and X-ray scattering facilities and for electron microscopy facilities. Shortfalls in the operating budgets for IPNS, SSRL and HFBR are resulting in lost research opportunities for BES. However, the shared mode of operation of SSRL with the High Energy Physics program may prevent improvements. (Note SSRL is supported in part by BES-Chemical Sciences.)

6. Technology and knowledge transfer activities, which are important to the economic competitiveness of the country, are receiving a great deal of attention in the Laboratory's OBES-DMS programs. In some instances this has led to the movement of key scientists to industry.

7. There is a growing educational function within OBES-DMS programs at the Laboratories; this takes the form, most importantly, of full-time Ph.D. thesis students and postdoctoral fellows being trained at the Laboratories.

Recommendations

The Subcommittee wishes to generally applaud the OBES-DMS program but also wishes to address the following recommendations to DOE management:

1. Materials research is of such great importance to the Nation's economic health that funding for BES-DMS programmatic research should be increased generally above inflation. One area of particular importance, high temperature superconductivity, should have funding increases of approximately 100% over the next three fiscal years (FY 1988, FY 1989, FY 1990). Included in this program should be solid state physics, solid state chemical synthesis and microsructural control of the superconductivity and mechanical properties. Advanced synthesis and processing science should receive more attention generally, especially with regard to opportunities in advanced semiconducors. The decline in the base program, i.e., that not related to operation of facilities, over the last few years needs to be reversed. The Laboratories' and Universities' programs need to remain strong across the breadth of basic materials research areas in order to allow for flexible response to new scientific opportunities or technological needs of the Nation.

2. Full funding of the operation of existing major facilities within appropriate technical limitations, including support of users programs, should be immediately established. New major users facilities for

materials Sciences research now under construction or planned should be operated fully and effectively, i.e., sufficient operating funds should be planned for in advance by OBES.

3. The OBES-DMS program must retain a focus on long term basic research and assure that freedom of information in publications and conferences is maintained. A dilution of the attention of BES to short-term activities related to product and process development would be damaging dto the Nation's materials research efforts in the long run.

4. The training of Ph.D. students and postdoctoral fellows and the visiting scientist/visiting faculty programs should be greatly enhanced. This will be the most effective means of technology transfer, i.e., the transfer of highly trained Ph.D.'s to industry.

In summary, the talent in materials research supported by OBES-DMS is generally of outstanding quality. The DMS program will certainly deliver new opportunities to the Nation in materials, processes, and facilities. We, however, need to be vigilant that short term competitiveness issues do not, in fact, kill the "goose that laid the golden egg" and thereby destroy the Nation's legacy for the future.

Appendix C

Subcommittee Report on Chemical Sciences, Biological Energy Research, and Carbon Dioxide Research

C. P. Flynn
M. L. Good
D. C. Hoffman
L. T. Silver
W. B. Travers
M. S. Wrighton (Chair)

Background

The above BESAC members met on August 7 and 8 at the Marriott O'Hare. DOE representatives of the three areas of subcommittee responsibility were involved on both days. The DOE representatives were Dr. F. D. Stevenson (Chemical Sciences), Dr. G. L. Dilworth (Biological Energy Research), and Mr. F. A. Koomanoff (Carbon Dioxide Research), and each made a presentation describing the DOE/BES program. On Saturday afternoon the subcommittee met privately to discuss the issues brought out in the informal dicussions and presentations. For additinoal background Mark S. Wrighton had met on June 27, 1987 with Dr. Robert Rabson, Director of Biological Energy Research and had also had telephone conversations with Dr. Robert S. Marianelli, Director of Chemical Sciences. Each of the BESAC members had also received copies of FY86 research summary books from the three programs.

Dr. F. Y. Fradin, also a BESAC member, was present for part of the meeting on August 8. Dr. Velmer A. Fassel (invited to join the the subcommittee) resigned from BESAC and did not attend the meeting. Dr. Joseph Macek, assigned to the subcomittee meeting, was not able to attend the subcommittee meeting.

Subcommittee Report

This brief report is intended to highlight issues relating to three BES programs: Chemical Sciences, Biological Energy Research, and Carbon Dioxide Research. The following three sections include observations and recommendations that need to be considered by BESAC as it prepares its December, 1987 report to the Director of the Office of Energy Research.

Chemical Sciences Division

The Chemical Sciences Division is a major source of research support in basic chemistry. Chemical Sciences has several objectivs including: building a knowledge base in chemistry for advanced energy technologies, extending boundaries of energy-related chemistry and atomic physics, operating certain of DOE's unique user facilities, and preparing and separating isotopes for research, medical and industrial use. The FY87 operating budget for Chemical Sciences, $115 million, is about the same as the NSF Chemistry Division budget, about $90 million. The Chemical Sciences budget includes Nuclear Sciences and contributions to the operation of user facilities (greater than $30 million). About 2/3 of the Chemical Sciences budget is spent in National Laboratories, the bulk of the remainder going to universities. It is clear that National Laboratory support from Chemical Sciences is very large whereas NSF support in National Laboratories is negligible. The following observations can be made regarding the Chemical Sciences:

1. In constant dollars there has been no growth in research, despite considerable progress and promise in the science. There has been a recognition that prioritizing research areas is necessary and research activities have been supported in areas encouraged by the NRC's "Pimentel Report" and supported by an ERAB study.

2. In the Chemical Sciences as a whole a large and growing fraction of total resources is being directed to facilities support. For many of the cutting edge studies in science, chemistry included, major instrumentation facilities are important. It is equally evident that facilities are also important dollarwise. One consensus point seems to be that research funds cannot provide the emergency resources that from time-to-time are needed to bail out a major facility. The research budget is already too thin to provide the backup funding for unexpected facilities contingencies.

3. In certain areas the Chemical Sciences program overlaps strongly the interests and activities of major industries. Such an area is catalysis. The Chemical Sciences Division needs to be sure to be aware of the industry programs in order to assure that research at the state of the art is being supported. For example, in the area of catalysis there are some industrial concerns with major programs covering aspects of catalysis that overlap the research interests of DOE grantees and contractors. The program monitors in the Chemical Sciences Division are encouraged to follow as closely as possible the developments in industry and to consult with industry research leaders to gain an understanding of the basic science needs in energy-related research in chemistry.

4. Chemical Sciences supports science that is unique, at the frontiers of science, and not supported elsewhere. Two examples in very different areas of importance are: (1) preparation and separation of isotopes, particularly transuranium isotopes and research on these and still heavier isotopes; (2) structural characterization of coal. The Chemical Sciences Division currently supports the strongest program in the U.S. in the area of photoconversion, including fundamental studies of the natural photosynthetic apparatus that has yielded insight into the mechanisms of solar conversion in plants. The program includes major efforts to duplicate the essential features of the natural photosynthetic system with man-contrived, abiological components. It is especially important to support (cf. "Opportunities in Chemistry" National Academy Press, Washington, D.C., 1985, pp. 260-261) further exploration of the chemistry of the upper end of the actinide series and beyond where relativistic effects on the atomic electrons should play an increasingly prominent role. Such studies require the use of transuranium isotopes produced at the HFIR-TPP facilities which are unique in the world and supported by Chemical Sciences

Biological Energy Research

A relatively new program, Biological Energy Research, has experienced real growth, even after adjustments for Congressionally mandated programs and construction, and the FY87 operating budget is about $17 million. The objective of Biological Energy Research is to provide the knowledge base for biological systems for energy production. The research is mostly carried out at universities, since the talent base is mostly in the academic arena. The following comments can be made about the program:

1. The program supports a wide range of activities with a wide variation in support levels per project reflecting well the relative needs of each endeavor. There is evidence that unique research at large funding levels is being established as in the area of structural characterization of complex carbohydrates. The program in carbohydrates stands to be a U.S. jewel.
2. It is likely that major industries will be built based on some of the science areas covered by the program and the BES staff should be aware of industrial research efforts to avoid duplication of industry efforts.
3. The program is urged to continue its cautious development of large programs to keep a healthy balance of research vs. support to maintain facilities and centers.
4. The activities of Biological Energy Research are wholly appropriate to the objectives of the Office of Basic Energy Sciences, since the emphasis is on basic science related to energy production. Transfer of Biological Energy Research to the Office of Health and Environment Research is not desirable, considering that the mission of OHER is more concerned with an understanding of the health and environmental effects associated with energy technologies.

Carbon Dioxide Research

The program in CO_2 research is relatively small, of the order of $12 million, and is intended to address the issues surrounding whether there are serious problems that will arise from the generation of CO_2 and other trace gases from the use of energy. The science needed is broad in scope and not tied to any one discipline. The activities of the program are diverse and the perception is that possible global problems will receive great attention from the public and Congress. The subcommittee's views are the following:

1. The Office of Basic Energy Sciences is certainly the proper organizational position for large complex systems studies of the sort connected with establishing the science base to address whether serious consequnces are associated with CO_2 and other trace gases.
2. Budgeting a basic science activity such as global models for the atmosphere through any DOE office other than BES is inappropriate. At least on this issue, there is need to change the organizational structure.
3. It is not clear that the present organizational structure is optimum. There are reservations concerning the mechanism by which research programs

were selected and whether they have been conceived by outstanding researchers or by the DOE leadership. Considering the complexity of the programs, scope of the potential problems, and the scrutiny this area will receive, the science needs to be very carefully conceived and executed.

4. There is enormous opportunity to contribute much new basic science on a global climate, owing in part to the revolution in computing power. A vigorous experimental program to properly test global models is desirable and encouraged. BES has a great opportunity to make a monumental contribution to understanding long term trends in global systems.

5. The entire membership of BESAC should condsider the issues surrounding research of CO_2. The opportunity is large, the visibility is high, the science is exciting, but the problems are (hopelessly?) complex and highly interdisciplinary.

Appendix D

Subcommittee on Basic Energy Sciences
Engineering and Geoscience

J. D. Bredehoeft, Chairman
D. E. Moncton
J. R. Rice
H. H. Richardson
L. T. Silver
W. B. Travers

Introduction

The earth and, therefore, earth science are critical to the missions of the Department of Energy. From the earth comes the fossil fuels which are the primary source of recoverable energy. In addition, the nation is attempting to utilize the earth to dispose of its toxic wastes, especially its military and industrial nuclear wastes. The nation also utilizes the earth as a test bed for nuclear weapons. DOE has major efforts in underground nuclear weapons tests, disposal of nuclear wastes, cleanup of toxic wastes, all of which have major geoscience and engineering activities associated with them. In the case of engineering, DOE has large applied R&D programs in fossil energy, solar and renewable energy sources, and nuclear systems which have associated with them applied engineering efforts aimed at their respective short-term needs.

It is apparent that another liquid energy crisis will be forthcoming. Economic forecasts indicate that in 1990, the U.S. may spend $120 billion for imported petroleum; by 1995, the cost could exceed $170 billion (in 1986, the U.S. balance of trade deficit from all sources was $156 billion). The U.S. currently imports about 45 percent of its oil, compared to 31.6 percent in 1982. Some time next year imports will surpass domestic production. The domestic petroleum industry, especially its exploration and research, has been badly damaged by the recent period of reduced prices for crude oil.

Research support

Support for both engineering and geosciences has grown steadily within BES from zero in 1979 to approximately $30 million in FY 1987, with approximately $15 million going to engineering and $15 million to geosciences. Both engineering research and earth science are important to the primary mission of the Department. To have the basic research in these areas funded at their current low levels of only about $15 million each seems inappropriate in relation to their importance to DOE.

One difference between the management of the BES engineering and geosciences research programs can be seen in the distribution of funding between the national laboratories and the university community. More than 50 percent of the engineering and approximately 25 percent of the geoscience program budgets go to the universities. The BES geoscience management has put more emphasis on DOE laboratory support than has the engineering program staff in the past several years.

ERAB Report

BESAC was not asked to comment on the ERAB report; however, we believe several remarks are in order. The report suggested that the highest research priorities be given low-risk, short-time research in fossil fuels, especially oil and gas. It further suggested that an office of geoscience research be established within DOE for the purpose of 1) administering a strategic research program, and 2) coordinating interagency as well as intra-agency research.

The ERAB report urged short-term, high-payoff research. While such pragmatic research may help in the near term, often it is the more basic, long-term research which yields fundamental discoveries which have sustained payoffs over long periods of time. It is important that a balance be struck between the short-term, more applied research advocated by ERAB and the long-term more basic research. We would urge that within BES particularly, the long-term basic research not be abandoned in favor of the short-term applied research. We believe that BES is the logical home for a long-term fundamental research program in the geosciences.

Currently the BES geoscience and engineering programs devote approximately 20 percent of their budgets or about $3 million each to research related to fossil-fuel problems. This amount for basic, long-term fossil-fuel research seems too small in view of its importance to the nation.

Basic Fossil Fuels Research

There are many critical generic research problems which both the ERAB panel as well as others have identified. For example, the remarkable variability in the physical and chemical properties of natural petroleum is well known but very little is truly understood about the fundamental physics and chemistry of "live" (i.e., in place) oil. *In situ* viscosity, surface properties, solubilities, chemical composition and fractionation mechanisms are among some of the key properties which help determine a petroleum's response to primary, secondary and tertiary recovery efforts. A generic basic research program aimed at understanding how petroleum "works," i.e., origin of its physical properties and a predictive guide to its responses to extraction efforts, might unlock some of the enormous quantities of "unproducible" oil now inaccessible to us.

Similarly, the nature of the physical and chemical interactions among petroleum, various aqueous fluids, and the assemblage of rock-forming minerals in which they are hosted, are still mysterious to reservoir engineers and production geologists. At a fundamental level our understanding of the rock properties and processes governing the transport of mass and energy in porous and fractured rocks requires a major research initiative to significantly raise the effectiveness of petroleum-extraction technology. This research would have broad application to many mineral and energy resources, mining, and waste-management problems.

Opportunities exist for the development of advanced technology in the areas of remote sensing, advanced drilling systems, reconnaissance and downhole geophysical measurements, well and oil field reservoir characterization, and advanced seismic applications to exploration. These research areas can be supported by DOE in universities, industry, other agencies, and the national laboratories, as well as in DOE-supported centers. Such support would be highly leveraging in that the results would be rapidly adopted both in industry and academia.

The ERAB panel identified "cross-cutting geoscience topics," among those identified are the dynamic behavior of rocks and fluids, methodology for modelling crustal prrocesses, testing of crustal models through scientific drilling, and exploring the environment of hydrocarbon generation in time and space.

There are sound arguments to be made that major DOE initiatives in basic petroleum should be directed at such fundamental problems using a multidisciplinary approach where geoscientists, physicists, chemists and engineers bring their disciplinary strengths together in different types of centers (e.g., university-based centers and national laboratories) than those proposed in the ERAB report.

The subcommittee feels that BES engineering and geosciencfes should take the lead within DOE to develop a major basic research initiative aimed at fossil fuels.

Impact of the Continental Drilling Program

The BES geoscience management team was perhaps the only management group within the federal government to recognize the importance of continental drilling to basic geologic research. They came to this realization almost a decade ago. Their faith has now borne fruit; a major new continental drilling program having been established at NSF.

In the last several years the BES geoscience program has directed a major part of its resources to the Continental Scientific Drilling Program (CSDP). CSDP currently accounts for approximately one third of the geosciences effort; the largest single category in the geosciences research budget is the management infrastructure created for CSDP.

Increased continued support for CSDP without an influx of additional funds will come at the expense of the traditional geoscience research program. The working group, while it applauds geosciences past accomplishments in continental drilling, questions the advisability of increased support for the CSDP without an influx of new funds.

To date the efforts in CSDP within BES for actual drilling have been restricted to so-called "thermal-regime" areas, which translates into areas of geothermal interest. With respect to geothermal energy, the several assessments of the U.S. geothermal potential which the Geological Survey has published suggests that it will be unlikely to obtain more than one or perhaps two percent of the nation's basic energy supply from geothermal energy. This is not to say that geothermal power is not important locally. However, it does not-appear likely that many more geothermal fields of the magnitude of the Geysers in California will be found. There does appear to be large supplies of moderately hot water which could be used for space heating. Unfortunately, many of the areas of interest are remote from centers of population. There is no doubt that many of the thermal-regime target areas are areas of geologic complexity and interest. However, in terms of an impact on the energy potential of the nation it would seem that a broader perspective that looks beyond "thermal-regime" targets is warranted.

Mass and Energy Transport in the Earth

One research theme pervades many of the earth-related problems of DOE. Stated in the broadest context this theme is "the transport of mass" (chemical constituents with chemical reactions and energy (heat) by moving fluids (groundwater as well as oil and gas) in the earth. There are a number of practical problems which fall into this classification; among them are: the production of oil and gas, the pumping of groundwater, the movement of contaminants in the ground, the development of geothermal power, the containment of underground nuclear blasts, solution mining, the enhanced recovery of hydrocarbons, the in-situ retorting of oil-shale, etc. Examination of the above list shows how inclusive this topic is. Research in this area cann provide a large payoff in terms of the problems facing both DOE and the country.

The working group examined the BES engineering and geoscience research programs wih the focus "mass and energy" transport by moving fluids. More than 50 percent of currently supported activities fall under this umbrella.

Within the engineering program many of the activities which involve mass and energy transport by fluids involve fluid flow at high Reynolds numbers. Often the flow is sufficiently high to involve turbulence. These are obvious problems for pipelines, especially where flowing gas and liquids coexist in the pipe.

Subsurface fluid flow in the earth is generally at low Reynolds numbers where only friction, not inertial or turbulent effects, are important. There is a class of reservoir engineering research currently underway which directly relates to subsurface geologic problems. In the current geoscience research program, approxmately 50 percent of the activities can be included under the general topic of mass and energy transport in the earth. There are perhaps two areas where the effort appears to be too small. The research on the physics of mass and energy is small in comparison with the other efforts. The current research on fossil fuels also appear to be small when one considers the importance of fossil fuels in our present supply of energy.

Basic Research in Energy Engineering

A report of the same title as this section was prepared in August 1986, for BES (ed. L. D. Witte and R. Eichhorn, U. Houston); four areas of research were identified:

1. Fluids, chemical and transport processes;
2. Solids, structural mechanics and dynamics;
3. Systems, instrumentation and control; and
4. Modern methods in energy systems

The report proposes a much broader array of fundamental engineering research than the present program accomodates. At present a preponderance of program's resources are in the first area listed above, fluids, along with related non-linear mathematics. Its coverage of other areas of the engineering sciences is spotty. It is not clear that the program successfully elicits or deals favorably with proposals for fundamental work in the other areas.

An appropriate new subfield to include in the program not envisioned in 1986 is on the engineering problems related to utilization of new high T_c superconductors. These pose new problems in structural and fracture mechanics, related to forces exerted on brittle current-carrying elements in strong electrical fields, in control theory relating to magneto-mechanical interactions, and in the thermal sciences among other areas.

Interactions of the engineering program with other elements of BES, and the converse, need to be better explored. For example, the commonality of basic approaches between engineering and geosciences on such topics as heat-and-mass transfer in moving fluids and on fracturing processes is discussed elsewhere. Another potential commonality is with materials science where engineering in fluid and solid mechanics, transport phenomena and instrumentation and sensing have the critical expertise necessary to advance economically pivotal areas in materials processing and manufacture.

Opportunities and Recommendations

1. Currently the BES engineering and geoscience research programs are considered independently of one another, and managed separately. An opportunity exists within BES for more research coordination, not only between geoscience and engineering but between other research programs in BES, including materials science and chemistry. BES could address fundamental research questions across a broad spectrum of disciplines.

2. Strategic plans should be developed for each of these programs which clearly state the mission and goals, the relevance of the programs to national energy issues, priority areas for support, and policies to be followed in selecting programs and investigators. In the case of engineering it is essential that a coherent rationale for selection of research areas be developed. The 1986 scoping workshop report, "Basic Research in Energy Engineering," referred to above, outlines needed research in four major areas: Fluids, chemical and transport processes; solids, structural mechanics and dynamics; Systems, instrumentation and control; and Modern Methods in energy systems. This study provides a basis for an engineering strategic research plan.

3. In considering areas of research, a review of the nation's energy consumption indicates dependence on fossil fuel far into the future. Basic generic research into important problems in fossil fuels is currently neglected and should be emphasized within the BES program. A meaningful research program in basic fossil-fuel research requires substantially increased levels of funding. As much as the subcommittee would like to recommend areas within the present engineering and geoscience programs to redirect, both programs are so small that redirection will not generate the support necessary for a significant fossil-fuel, research program.

4. Mass and energy transport by moving fluids in which chemical reactions are

occurring is a pervasive problem in energy systems. It is one of those broad areas of reasarch which, if it could be better understood, would be applicable to a number of practical problems confronting the DOE and the nation. While this area was defined in the 1986 engineering scoping workshop as one of the four thrust areas for the engineering program, little emphasis has been given to it in funding. Since a significant amount of research is supported in the area by the Chemical Sciences Division of BES,there should be a strong effort, possibly formalized through joint planning, to coordinate among geosciences, engineering, and the chemical sciences research in fluid, chemical and transport processes.

5. Continental drilling affords exciting opportunities to advance geoscience. At some point one must drill into the earth to verify what up to that point is an hypothesis. Drilling, while it is critical to advancing geologic knowledge, is expensive. A continued, enhanced CSDP must be provided with additional "new" money in order to avoid the erosion of support for other worthwhile geosciences research.

U.S. ENERGY FUTURE TO 1995

A Report to the Basic Energy Sciences Advisory Committee

by

William B. Travers

October 14, 1987

Revised October 14, 1987

U.S. ENERGY FUTURE TO 1995

In 1990, the U.S. may spend $120 billion for imported petroleum. By 1995 the cost could exceed $170 billion. In 1986, the U.S. balance of trade deficit from all sources was $156 billion. This is 4% of GNP and about equal to recent annual growth in GNP. The U.S. currently imports about 45% of its oil compared to 31.6% in 1982. Some time next year, imports will surpass domestic production.

Economic consequences of such payments for foreign oil are not entirely clear; however, at least a doubling in the prices of gasoline, home heating oil, and energy for industry are predictable. The consequent drop in U.S. standards of living will be accentuated as the huge foreign debts are repaid, probably by rising income taxes as well as increased prices.

Large petroleum reserves remain undiscovered in the U.S. and even larger quantities remain to be extracted from known fields by breakthroughs in enhanced oil recovery (EOR) sciences and technologies. Exploration success ratios remain high. Currently about 15% of U.S. wildcat wells discover petroleum compared to slightly less than 20% success in 1980, the best recent year.

However, today's exploration and EOR activities in the U.S. are inadequate to raise production. As U.S. demand rises and our production capacity begins to fall, the U.S. will become increasingly dependent on foreign oil. Since U.S. refining capacity is not growing, an even larger portion of imported oil will be refined products. Current prices for imported crude oil are about $20 per barrel, while refined oil prices average approximately $34 per barrel. Refined oil is now 32% of imports and will be 50% of imports by 1995. At that time, crude oil may cost $35 per barrel and refined imports will probably be near $50 per barrel. If so, in 1995, the U.S. will pay a $42.50 average price for approximately 4 billion barrels of imported crude plus refined products, costing 170 billion 1995 dollars.

Can the U.S. do anything to stop or slow its use of foreign oil? Could domestic oil production be made to rise quickly in response to a sudden energy crisis such as the cut-off of Persian Gulf oil or a sudden jump in prices?

A glance at recent U.S. production history is not encouraging. Since 1970, U.S. oil production has remained constant at about 3 billion barrels per year, but reserves have declined greatly from 46 to 28 billion barrels. Consequently, production must begin to decline soon, perhaps sharply. Natural gas reserves have dropped from 360 TCF (trillion cubic feet) to 150 TCF in the period 1970 to 1986; recently oil prices have risen, but natural gas prices have not, so exploration for gas is at the lowest level in two decades. Probably 1500 TCF remain to be found in the U.S. (excluding Alaska, since no gas pipeline exists). 1500TCF can be found only if we greatly increase exploratory drilling. 1500 TCF is a 90 year supply at the current use rate of 17.4 TCF per year.

The DOE estimates that 168 billion barrels of oil remain to be discovered in the U.S. by wildcat exploration or recovery from known fields by enhanced oil recovery techniques. Given current total U.S. demand, 168 billion barrels could supply all the U.S. for 25 years, or 50 years at current production rates. World reserves of oil and tar exceed 9000 billion barrels, enough to last nearly 300 years, even assuming the world uses twice as much oil, on average, as it does today. 42% of world reserves are known to be in the Westsern Hemisphere, mostly in Canada and Venezuela.

Enhanced oil, heavy oil, and tar production require at least a decade to develop, but exploration for these fields has dropped dramatically. In 1981, 17,430 wildcat wells were drilled and 8172 seismic crews explored for petroleum. In 1986, the U.S. drilled only 8184 exploratory wells and only 2355 seismic crews were at work.

At least ten years is needed to train and develop exploration teams. A similar period is needed for petroleum engineering and extraction teams. The U.S. Petroleum industry had more than 65,000 geologists, geophysicists and petroleum engineers in 1985. Now there are fewer than 35,000. Petroleum scientists and engineers who were fired from oil companies have begun careers outside the petroleum industry. They are not likely to return to the petroleum industry. Industry labs are not only contracting, they are focusing on technology transfer more than research. Undergraduate enrollments in geology and petroleum engineering in U.S. universities are less than 30% of peak years. The U.S. petroleum industry does not have, and cannot quickly obtain and train, scientists and engineers to respond immediately to a future oil crisis.

Many oil company research laboratories have closed. Those that remain open have many fewer scientists and research engineers than previously. Staffs necessary to find new oil, to recover old oil, enhance the fraction of oil recovered from active formations and learn more about heavy oil and tar recovery are too small. The U.S. petroleum industry is not now preparing to reduce the shock of huge payments for foreign oil in 1990 to 1995 (a $5 increase in oil price, perhaps through the proposed import tax, would help stimulate exploration and research.)

In addition to the importance of advancing exploration and extraction technology, and ensuring adequate talent for the benefit of the U.S. domestic petroleum industry, the decline in exploration and in petroleum-related engineering and scientific research in the U.S. raises serious concerns regarding the future energy, economic and military security of the U.S. The Soviet Union produces more oil than any other nation and is rapidly expanding its nuclear energy capacity. If the great decline of U.S. exploration and production capacity continues, the Soviets will be in an increasingly powerful position to use oil as a political tool, especially in Europe, and to generate cash to buy western technology.

Stimulating exploration activity requires economic incentives for the U.S. industry and is outside the scope of BESAC's mission. Advancing fundamental scientific and engineering knowledge for enhanced exploration and recovery of petroleum, and encouraging an adequate supply of engineering and scientific talent, are within BESAC's advisory scope. It is recommended that DOE and, specifically, BES recommend funding for a significant national initiative in fundamental scientific and engineering research and training for petroleum exploration and extraction. Also, this initiative should emphasize fundamental research for petroleum conservation.

The ERAB report recommends that six national petroleum research centers, associated with universities rather than the national laboratories, be established for the development of better exploration and recovery techniques, and for the training of petroleum engineers and scientists.

We should endorse the concept of increased DOE research in petroleum exploration, recovery and conservation. However, what is needed is not so much major centers, as a coherent national program of fundamental research centered in universities and national labs, and appropriate federal state agencies, with industrial cooperation, and that has sufficient, competitive federal funds to command the best U.S. talent for research and training. It is important that this be an interdisciplinary activity involving engineers, geologists and other scientists.

Appendix E

Subcommittee on Applied Mathematical Sciences Research

J. D. Bredehoeft
F. Y. Fradin
J. Macek (Chair)

The Applied Mathematics program has not been closely examined by this committee, but a key organizational issue has been identified, namely, the Applied Mathematics program was removed from OBES in 1985 and placed in a separate office reporting to the Director of Energy Research. The program is still budgeted through OBES. Concurrent with the new organization was a doubling of the applied mathematics portion of the OBES budget. The funds to support the computing network were transferred from the Office of Fusion Energy. A large Congressional initiative (Florida State University) partially accounts for the substantial increase in the Applied Mathematics budget. At present, funds for the FSU operation have not been budgeted by the administration even though the new facility is on line. A permanent budget category for this part of the Energy Research Computation network is needed. The subcommittee recommends that BES sister programs in Energy Research transfer a proportionate share of the costs of the FSU operation into the BES-Applied Mathematics base program and that BES should continue support of the FSU facility subject to a peer review of its operation.

Since concrete physical problems motivate applied mathematics research in the Department of Energy, and since the new organizational structure separates the Applied Mathematics program from the physical science programs, the subcommittee has strong reservations about the new organizational structure. We recommend closer scrutiny of this program by BESAC in the next year and suggest expanding the membership to include representation in the Applied Mathematics discipline.

Appendix F

Subcommittee Report on Advanced Energy Projects Research

C. P. Flynn (Chair)
F. Y. Fradin
M. Rowe
J. Macek

Background

Two members of the AEP subcommittee, Drs. Flynn and Rowe, met with the AEP director, R. Gajewski, in Shady Grove, where the director explained his future plans and answered questions. A report on this activity can be found in the minutes of the April meeting of the full BESAC committee. The committee also employed several documents supplied to it by Dr. Gajewski. These include:

Report DOE/ER-0294 AEP FY1986 Research Summaries,
Report JSR-86-302 JASON report "HEAVY ION FUSION II"
Material from BESAC briefing at the December and April meetings,
"Review of the Department of Energy's Inertial Confinement Fusion Program"...NAS report, March 1986.

Draft Report

The core program of AEP consists of high-risk, high-payoff projects that escape the funding nets available in other programs. Scientifically meritorious but unconventional projects with high potential return are selected. These projects are typically funded at $250K/year for three years. The BESAC subcommittee strongly supports this program concept and believes it to be a valuable and necessary channel for BES funding.

The subcommittee finds the core program well conceived and appropriate to the goals and character of the AEP program. The identification of projects generally requiring less than $1M annually for a period of three years has worked well. Projects have indeed been picked up by other agencies, developed for commercialization, or terminated in a three year time period. Continuation of this activity within BES is highly desirable.

Because the selection of projects is made primarily by the director, the subcommittee decided to review a sample of the proposals that have been funded. The five proposals reviewed by the subcommittee all received high marks for originality and overall quality. The subcommittee finds that the present method of selecting proposals for support is sound.

In addition to the "core" of the program, AEP also supports a long term project in Heavy Ion Fusion Accelerator Research (HIFAR). This project was transferred from Defense Programs to OER in 1983 and eventually came under the direction of AEP. An emphasis on commercial applciations separates this project from others located in Defense Programs. Its principal objective is to develop a data base for future decisions on an appropriate driver for inertial confinement fusion for commercial power generation. Early designs have been successful and the project now requires an additional $26M over a four year period to complete the next phase of research.

By design the HIFAR project does not address many key issues of inertial confinement fusion including reactor vessel design, materials research and target-driver coupling. Responsibility for pellet design is centered in Defense Programs, and since pellet-driver coupling is viewed as a key issue, close coordination between the project in Defense Programs and the HIFAR project is essential. The subcommitee is concerned that the present organizational structure for the commercial inertial confinement fusion project may be less than optimal and recommends closer scrutiny of this issue, probably by the BESAC advisory committee.

The HIFAR project has been favorably reviewed by the JASON group in 1986. Also, an NAS committee reviewed DOE's inertial confinement fusion program in 1985 and published its report in March of 1986. These reports support an accelerator-based program. The committee is concerned, however, that considerably expanding the HIFAR project at this time may be premature. To establish the relative merits of the HIFAR project, a comprehensive review of all presently supported fusion programs is needed. The subcommittee recommends that such a review be undertaken at an appropriate management level in DOE. The advisability of expanding the HIFAR project at this time could then be assessed in view of priorities for the whole fusion effort.

Appendix G

UNIVERSITY OF ROCHESTER

ROBERT L. SPROULL
PRESIDENT EMERITUS
AND PROFESSOR OF PHYSICS

301 BAUSCH AND LOMB HALL

April 29, 1987

Dr. James F. Decker, Acting Director
Office of Energy Research
U.S. Department of Energy
Mail Stop 7A140
1000 Independence Ave.
Washington, D.C. 20585

Dear Jim:

I am writing on behalf of DoE's Basic Energy Science Advisory Committee. As you know, this Committee is young and we should rather spend many months informing ourselves and maturing our judgment before making any reports or recommendations. But there are two highly important issues that are also urgent, and I have been instructed by the Committee to write you with the following two recommendations.

The first is a problem and is the loss of use of the HFIR at ORNL. We need not repeat to you the vital service of this reactor in all of its three modes, nor can we help you sort out the various alternatives. But we do wish to recommend in the strongest possible terms that a way must quickly be found to put this reactor back into operation, even if necessary at a somewhat reduced flux level.

The second is an opportunity and is the remarkable development of high T_c superconductors. Such an opportunity comes only a few times per century, and it would be a great loss if other countries exploited it more rapidly than the United States. Of course there will be great commercial effort, and DoD and NSF can be expected to step up to the opportunity. Also, we expect other elements of DoE will expand programs to take advantage of the new developments. Nevertheless, the mission of Basic Energy Sciences requires that a major effort be mounted, primarily in the Materials, Chemistry, and Engineering Programs. We strongly recommend that $30 million be added to the BES 1989 Budget for research and advanced development on high T_c superconductors.

Respectfully submitted,

Robert L. Sproull, Chairman
Basic Energy Sciences Advisory Committee

Department of Energy
Washington, DC 20585

MAY 19 1987

Dr. Robert L. Sproull
Chairman, Basic Energy Sciences
Advisory Committee
201 Bausch and Lomb Hall
University of Rochester
Rochester, New York 14627

Dear Bob:

Thank you for your letter of April 29 expressing the will of the Basic Energy Sciences Advisory Committee to bring to my attention two important and urgent issues, namely HFIR and high T_c superconductors.

We share with BESAC appreciation of the importance of HFIR to the scientific community and the desire to get it back on line with a minimum of further delay. Unfortunately, it is taking a longer time than was anticipated to develop an accepted understanding of the state of the pressure vessel and under what operating parameters the reactor may be safely operated. It may cost between 20 and 50 million dollars to upgrade the plant, none of which has been budgeted in either the FY 1987 or FY 1988 budgets. From discussions of your letter with Don Stevens, it is my understanding that the Committee's intent was to urge restart of HFIR, but not at the expense of other activities underway. We are working on this problem and what to include in our FY 1989 budget request, even though the analysis of the reactor is incomplete.

On the matter of high T_c superconductors, BES, mainly Materials Sciences, is currently supporting research on these materials at a level of approximately $10M, annualized, mainly through redirection of other research efforts. Promising additional projects will be supported both this year and next, and an initiative in FY 1989 is under serious consideration.

I appreciate your taking the time and effort to inform us of BESAC's expression of urgency on these matters in time to be considered in the formulations of the FY 1989 budget request. It would be difficult to work something into this budget at a later date.

Sincerely,

James F. Decker
Acting Director
Office of Energy Research

Appendix H

BES Budgets and Personnel by BESAC Subcommittes

BESAC Subcommittee	FY 1987 Operating Budget (M$)	Division Director
Materials Sciences	153.1	I. Thomas
Chemical Sciences (CS), Carbon Dioxide Research (CDR) and Energy Biosciences (EB)*	141.4 2)	R. Marianelli (CS) F. Koomanoff (CDR) R. Rabson (EB)
Advanced Energy Projects	12.6	R. Gajewski
Applied Mathematical Sciences 1)	38.3	D. Austin 3)
Engineering and Geosciences	29.0	J. Coleman
	374.4 2)	

Notes: 1) The Applied Mathematicsl Sciences program is budgeted under BES, but organized outside BES.

2) The Carbon Dioxide Research program is budgeted elsewhere and organized within BES (13M$ is included in this sum).

3) Acting.

* Formerly Biological Energy Research

BES Distribution of Operating Funds

FY 1987 Operating Funds - 361.4M$

1) Major Facilities

Of the total operating budget, 17% is allocated to the operation of major user facilities. These major user facilities include: SSRL, NSLS, HFBR, HFIR, CRF, IPNS, and LANSCE.

2) University and DOE Laboratories

Research underway in BES, exclusive of the operation of major user facilities, takes place primarily at universities and DOE laboratories:

		Percent
Universities	-	28
Laboratories	-	52
Major Facilities	-	17
Other	-	3
		100

Appendix I

Department of Energy
Washington, DC 20545

AUG 3 1987

Dr. Robert Sproull
President Emeritus
University of Rochester
201 Bausch & Lomb Hall
Rochester, NY 14627

Dear Bob:

This letter is in response to the request by several members of BESAC for information on BES project "turnover". Don Stevens asked Dave Richman of his staff to develop the requested information herewith presented.

Gathering such information is not as easy as it sounds. As you know, our projects are administered in essentially two ways: through the National Laboratories, and through our headquarters administered contract/grant program.

Data relevant to the "turnover" question for our research projects (approximate total funding level of $300,000,000) is provided in the three tables enclosed.

Table 1 is for research projects supported at or through the National Laboratories. This data was obtained from the labs. It excludes projects that are primarily for support of facility operations or services, e.g., to operate HFBR or to administer the stable isotopes sales program at ORNL. Also generally excluded by the laboratories from this data are "projects" for support of assessment or program management support projects, meetings, or conferences.

Some of the laboratory "projects" identified actually are comprised of several relatively large "subprojects". Most, however, are at the "subproject" or "task" level. Further breakdown of the larger projects would undoubtedly lead to an increase in the identified turnover of lab "projects" since program content in many long-term projects has changed significantly as new science has been revealed, and as DOE missions have been redefined. The current program activity in high temperature superconductivity demonstrates this point. A number of BES supported groups have clearly altered their directions with BES encouragement to follow this important, timely area. Thus the turnover rate of national laboratory research projects is most probably higher than calculated.

For the ten year period from 1977 through 1986, the "average" turnover rate of National Laboratory research projects was 12.1 %. The "average" age at termination was 8.4 years.

Table 2 is for BES nonlaboratory contract and grant supported projects. These projects are overwhelmingly carried out at universities, although they do include research supported at industrial, not-for-profit, and other federal agency laboratories.

A significant complication in compiling data is that for the past several years we have been converting special research contracts to grants. Thus available data bases show terminations for projects that actually are continuing but under a grant rather than a contract. We have made every effort to avoid including project terminations that really are not terminations in the data reported here. Similarly, we have avoided including as a termination cases where research projects continue although the principal investigator moves from one university to another.

At the beginning of 1986, BES had 827 nonlaboratory projects. About 20 of them were for conferences, short term studies, etc. and typically had terms of from 1 to 3 years. Thus the average turnover rate under the nonlaboratory contract/grant program for research activities would be very slightly below the calculated figure in table 2 of 13.1 %.

Tables 1 and 2 show a total of 1304 projects in effect at the beginning of FY 1987.

Table 3 estimates, based on the data we have on new starts and terminations, the age composition of our current nonlaboratory contract/grant program portfolio. Because most of the projects have been shifted from contracts to grants during the past several years, a search of our files for actual data would lead to erroneous results. The average age of our contract/grant program projects is between 3 and 4 years. Less than 5% is more than 7 years old. While there may be wide error bars on these estimates, they are consistent with the data available, with previous studies and with our own perceptions.

I would like to add for your information that BES staff and National laboratory management all were helpful in compiling the data in the spirit of the BESAC request. I trust this meets your needs.

Sincerely,

Lou

Louis C. Ianniello
Deputy Associate Director
for Basic Energy Sciences

Enclosures

REPORT ON TURNOVER 30-Jul-87

TABLE 1. TURNOVER AT THE NATIONAL LABORATORIES

FISCAL YEAR	NO OF PROJECTS AT START OF YEAR	NO OF PROJECTS TERMINATED	NO OF PROJECTS STARTED	NO OF PROJECTS AT END OF YEAR	PERCENT OF PROJECTS TERMINATED	"AVERAGE" YEARS OF SUPPORT AT TERMINATION	CUMULATIVE AVERAGE TURNOVER
1977	295	26	36	305	8.8%	11.3	8.8%
1978	305	22	37	320	7.2%	13.9	8.0%
1979	320	42	50	328	13.1%	7.6	9.8%
1980	461	43	63	481 *	9.3%	10.7	9.6%
1981	506	63	63	506	12.5%	8.0	10.4%
1982	506	84	67	487	16.6%	6.0	11.7%
1983	487	59	56	487	12.1%	8.3	11.8%
1984	487	57	54	483	11.7%	8.5	11.8%
1985	483	69	59	470	14.3%	7.0	12.1%
1986	470	56	60	478	11.9%	8.4	12.1%
1987	478	N/A	N/A		N/A		

* Initial data for some labs not available until 1980 or 1981

* * * * * * * * * *

TABLE 2. TURNOVER AT UNIVERSITIES, ETC.

FISCAL YEAR	NO OF PROJECTS AT START OF YEAR	NO OF PROJECTS TERMINATED	NO OF PROJECTS STARTED	NO OF PROJECTS AT END OF YEAR	PERCENT OF PROJECTS TERMINATED	"AVERAGE" YEARS OF SUPPORT AT TERMINATION	CUMULATIVE AVERAGE TURNOVER
1977	255	25	65	295	9.8%	10.2	9.8%
1978	295	37	97	355	12.5%	8.0	11.3%
1979	355	38	152	469	10.7%	9.3	11.0%
1980	469	67	171	573	14.3%	7.0	12.2%
1981	573	79	182	676	13.8%	7.3	12.6%
1982	676	110	158	724	16.3%	6.1	13.6%
1983	724	104	125	745	14.4%	7.0	13.7%
1984	745	98	124	771	13.2%	7.6	13.6%
1985	771	84	140	827	10.9%	9.2	13.2%
1986	827	102	101	826	12.3%	8.1	13.1%
1987	826	N/A	N/A				

* * * * * * * * * *

REPORT ON TURNOVER 30-Jul-87

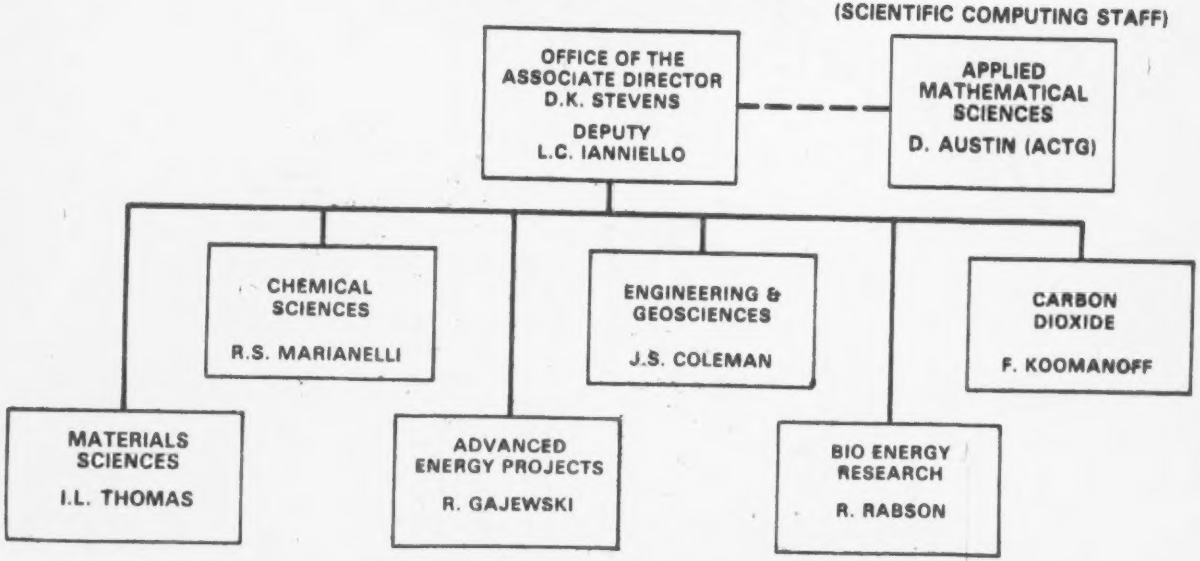
TABLE 3. AGES OF ONGOING NON-LABORATORY PROJECTS

FISCAL YEAR	NO OF PROJECTS STARTED	NO OF THESE REMAINING IN 1987	AGE OF CURRENT CONTRACT/ GRANTS	PERCENT OF ONGOING CONTRACT/ GRANTS	CUMU-LATIVE PERCENT
pre-1977		10	> 10 YRS	1.2%	1.2%
1977	65	2	9-10 YRS	0.2%	1.5%
1978	97	4	8-9 YRS	0.5%	1.9%
1979	152	19	7-8 YRS	2.3%	4.2%
1980	171	85	6-7 YRS	10.3%	14.5%
1981	182	121	5-6 YRS	14.6%	29.2%
1982	158	122	4-5 YRS	14.8%	43.9%
1983	125	109	3-4 YRS	13.2%	57.1%
1984	124	116	2-3 YRS	14.0%	71.2%
1985	140	137	1-2 YRS	16.6%	87.8%
1986	101	101	0-1 YRS	12.2%	100.0%
1987	N/A	N/A			

Appendix J

OFFICE OF BASIC ENERGY SCIENCES (BES)

ORGANIZATION


(SCIENTIFIC COMPUTING STAFF)
OFFICE OF THE ASSOCIATE DIRECTOR D.K. STEVENS
DEPUTY L.C. IANNIELLO
APPLIED MATHEMATICAL SCIENCES
D. AUSTIN (ACTG)
CHEMICAL SCIENCES
R.S. MARIANELLI
ENGINEERING & GEOSCIENCES
J.S. COLEMAN
CARBON DIOXIDE
F. KOOMANOFF
MATERIALS SCIENCES
I.L. THOMAS
ADVANCED ENERGY PROJECTS
R. GAJEWSKI
BIO ENERGY RESEARCH
R. RABSON

NOTES: 1) BUDGETS ALSO CONTAIN APPLIED MATHEMATICAL SCIENCES SUBPROGRAM
2) BUDGETS DO NOT CONTAIN CARBON DIOXIDE RESEARCH SUBPROGRAM
3) BUDGETS LIST BIO ENERGY RESEARCH AS ENERGY BIOSCIENCES

12/87

Appendix K

THE SECRETARY OF ENERGY
WASHINGTON, D.C.

November 24, 1986

Dear Dr. Sproull:

I am pleased to invite you to serve as a charter member of the Department of Energy's Basic Energy Sciences Advisory Committee. In addition, I would like to request that you serve as the first Chairperson of the Committee. This Committee reports to me through the Director, Office of Energy Research, U.S. Department of Energy, and advises me on the scientific aspects of a range of important matters relating to the Basic Energy Sciences program.

As a Committee member, you would have a very important responsibility to provide sound advice on the Basic Energy Sciences program. As Chairperson, your leadership and good judgment would contribute greatly to the Committee's effectiveness. The members are being selected to provide the Committee with balance in professional expertise, type of institutional affiliation, and geography. Copies of the Committee's charter and invited membership list for the coming year are enclosed.

I would be pleased by your willingness to serve as a member in the key role of Chairperson of the Basic Energy Sciences Advisory Committee, and will value your contributions to the important issues faced by the Committee this year.

The members of the Committee serve without compensation. Their travel and per diem expenses are covered through the Department's support of their home institutions, or directly by the Department.

Dr. Donald K. Stevens, Associate Director for the Office of Basic Energy Sciences, or a member of his staff, will be in contact with you concerning your acceptance of this appointment and to provide you with details about the administrative procedures of the Committee and the date of the initial meeting.

Yours truly,

John S. Herrington

John S. Herrington

Enclosures

Dr. Robert Sproull
President Emeritus
201 Bausch & Lomb Hall
University of Rochester
Rochester, New York 14627

Department of Energy
Washington, DC 20585

DEC 3 1986

Dr. Robert Sproull
President Emeritus
201 Bausch & Lomb Hall
University of Rochester
Rochester, NY 14627

Dear Bob:

Thank you for being willing to serve as the first Chairman of the newly established Basic Energy Sciences Advisory Committee. This is an important activity and I know that you will give it the attention it deserves.

The Department's Basic Energy Sciences (BES) Program is one of the nation's most significant in terms of the basic research programs it supports. These programs provide the intellectual basis for current and future energy technology developments, as well as the facilities for several areas of basic studies in chemistry, physics, mathematics, materials, etc. The programs involved have a long history, going back to the establishment of the Atomic Energy Commission in the late 1940's.

As a first activity for this new Advisory Committee, I would like you to undertake a broad review of the entire BES program. This will help the committee in establishing a good understanding of the various program elements and their interrelations, as well as the program's relation to the rest of the Department. Your review should examine the current activities of BES, taking into account the need for excellence in the various program elements.

One of the most useful functions of an advisory committee, apart from expert examination of contemporary activities, is to help identify future program needs and opportunities. What will the basic research opportunities be in the future and how should BES go about planning to meet them? What kinds of new facilities will be needed and when? What facilities might become obsolete?

I realize that a complete review of the program, and an analysis of the future needs, is a tall order and cannot be done overnight. Even so, I would like to have the committee meet again in late March, 1987, and review whatever material it has developed through subcommittees and studies it may have instigated. A final report by the Committee should be submitted by mid-December, 1987.

Sincerely,

Alvin W. Trivelpiece
Director, Office of
Energy Research

DEPARTMENT OF ENERGY

CHARTER

BASIC ENERGY SCIENCES ADVISORY COMMITTEE

1. Committee's Official Designation:

   Basic Energy Sciences Advisory Committee (BESAC)

2. Committee's Objectives and Scope of Activities and Duties:

   The activities of the Basic Energy Sciences Advisory Committee include:

   a. Periodic reviews of elements of the Basic Energy Sciences (BES) program and recommendations based thereon;

   b. Advice on long-range plans, priorities, and strategies to address more effectively the scientific aspects of energy-related basic energy sciences issues of departmental policies and programs;

   c. Advice on appropriate levels of funding to develop those plans, priorities and strategies and to help maintain appropriate balance between competing elements of the BES program;

   d. Advice on scientific aspects of basic energy sciences issues of concern to DOE as requested by the Secretary or the Director of Energy Research.

3. Time Period Necessary for the Committee to Carry Out Its Purpose:

   In view of the goals and purposes of the Committee, it is expected to be continuing in nature.

4. Official to Whom This Committee Reports:

   The Committee will report to the Secretary of Energy through the Director of Energy Research.

5. Agency Responsible for Providing Necessary Support for This Committee:
The Department of Energy. Within the Department, primary support shall be furnished by the Office of Energy Research.

6. Description of Duties for Which the Committee is Responsible:
The duties of the Committee are solely advisory and are stated in Paragraph 2, above.

7. Estimated Annual Operating Costs in Dollars and Person-Years:
$75,000; 1/2 person-year.

8. Estimated Number and Frequency of Meetings:
The Committee will meet approximately 4 times a year, at least once each quarter.

9. Committee's Termination Date (If Less Than 2 Years from Date of Establishment or Renewal):
Not applicable.

10. Subcommittee(s):
To facilitate the functioning of BESAC, subcommittees may be formed. The objectives of the subcommittees are to make recommendations to the parent committee with respect to particular matters related to the responsibilities of the parent committee. Ad hoc members from outside BESAC may be appointed by the subcommittee chairperson to ensure the expertise necessary to conduct the subcommittee's business.

11. Members:

    a. Committee members shall be appointed by the Secretary of Energy.

    b. Approximate number of Committee members: 17

    c. Membership terms shall be for a period of 1 year. Committee members may be reappointed to additional terms following review. No member may be reappointed for more than four consecutive 1-year terms.

12. Chairperson:

    The Chairperson shall be appointed by the Secretary of Energy.

This Charter for the Advisory Committee named above is hereby approved on:

October 16, 1986
Date

Charles R. Tierney
Advisory Committee Management Officer

October 16, 1986
Date Filed

DOE/ER-0358

REPORT OF THE
BASIC ENERGY SCIENCES ADVISORY COMMITTEE

PANEL ON HIGH-T_C SUPERCONDUCTING MAGNET APPLICATIONS IN PARTICLE PHYSICS

December 1987

U.S. Department of Energy
Office of Energy Research
Washington, D.C. 20545

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Attachment 1 - Letter from Alvin W. Trivelpiece, Director, Office of Energy Research, to Dr. Robert Sproull dated April 23, 1987 29

Attachment 2 - Meeting Agenda of the Panel on High Temperature Superconductors, July 7, 1987, Hyatt Regency, Washington, D.C. 31

Attachment 2a- Meeting Agenda, September 14-15, 1987, Lawrence Berkeley Laboratory, Berkeley, California 33

Attachment 2b- Meeting Agenda, October 23, 1987, AT&T Bell Laboratories, Murray Hill, New Jersey 35

Panel Members

Dr. Albert Narath (Chairperson)
AT&T Bell Laboratories

Dr. David F. Clarke
IBM, T. J. Watson Research Center

Dr. Frank Y. Fradin
Argonne National Laboratory

Prof. Fred Lange
University of California, Santa Barbara

Prof. David C. Larbalestier
University of Wisconsin

Dr. David E. Moncton
Exxon/Argonne National Laboratory

Dr. D. Bruce Montgomery
Massachusetts Institute of Technology

Prof. Francis C. Moon
Cornell University

Prof. George F. Reiter
University of Houston

Executive Summary

On April 23, 1987, Dr. A. W. Trivelpiece requested that the Basic Energy Sciences Advisory Committee study the possible use of the recently discovered high-temperature oxide superconductors for magnetic-field generation in particle-physics accelerators. He asked that the study focus on the technical requirements of the Superconducting Super-Collider (SSC) as a benchmark. The Panel which was organized to conduct this study examined three specific issues as directed: (a) the status of high-T_c superconductivity together with the materials requirements for accelerator applications; (b) technical obstacles to be overcome; and (c) time scale for development. The following summarizes the principal findings and conclusions.

The material requirements for a high-T_c SSC dipole magnet operating near 77K are not substantially different from the current Nb-Ti baseline. Filamentary conductors of 5-10μm diameter in contact with a stabilizing cladding of high-conductivity metal (e.g., copper) will be needed to assure adequate field uniformity. The superconductor must support transport current densities greater than 10^5A/cm^2 in an external field of ~7T. Individual composite filaments must be aggregated into conductor cables with carefully optimized geometry (i.e., cross-section; filament distribution; conductor twist). The cables must be capable of carrying currents in the range 5,000 - 10,000A, and have sufficient strength and toughness to survive severe mechanical stresses during coil winding and subsequent magnet operation.

Although not yet demonstrated, there is reason to believe that the candidate material yttrium barium cuprate ($YBa_2Cu_3O_7$) could with further development satisfy the critical-current and critical-field requirements. Magnetization measurements on single crystals and thin films have shown that local critical-current densities in these oxides can be very high ($J_c \approx 10^6$A/cm^2 in zero applied magnetic field and T=77K); transport critical-current densities of similar magnitude have been observed in some cases. However, polycrystalline samples to date exhibit much lower transport J_c values which, moreover, decrease rapidly with increasing field strength. The low ratio of transport to magnetization current densities in polycrystalline samples has been attributed to "weak links" caused by grain boundaries and, perhaps, other crystal defects. Suppression of the "weak-link" behavior is an essential requirement if these materials are to be considered for high-field magnet applications. In this regard it is encouraging that transport critical-current densities of ~10^3A/cm^2 (H = 1T; T = 77K) have recently been reported in bulk ceramic specimens in which the crystallographic c-axes were partially aligned. Among the important issues which need to be addressed is the role of grain and twin boundaries in limiting critical-current densities, especially in regard to dependence on crystallographic orientation, microstructure, and crystal chemistry. Flux-pinning centers need to be identified and methods devised for their controlled introduction.

Because of the stringent requirements placed on the superconducting cable, the coil winding process, and magnet operating characteristics, significant materials science and engineering issues are associated with all phases of magnet development. For this reason the Panel considered it important to define "materials development" for purposes of the present study as extending from the establishment of fundamental materials properties all the way through demonstration of prototype magnets. The assessment of technical obstacles and time scales was based on a conceptual development plan consisting of five overlapping program phases. Under optimistic conditions, it should be possible to develop designs and processes leading to demonstration of continuous lengths of composite (i.e., normal-metal stabilized) filamentary (5-10μm diameter) superconductor in about 4 years. It is estimated that another 8 years would be needed to develop an acceptable conductor cable and winding technique, and to demonstrate these in a full-scale accelerator-quality dipole magnet. This estimate assumes a level of effort comparable to that of the current SSC magnet program. Since the cost benefits of high-T_c superconducting magnets for particle-physics accelerator application appear marginal at this time, the actual development pace might be slower. (This conclusion could change in the event that new materials are discovered with far superior properties, particularly in regard to critical temperature, chemical stability and ductility.) On the other hand, a more aggressive program than assumed, while capable of reducing development risks, would not necessarily compress the schedule significantly. Accelerator magnets of the type considered here are among the most complex superconducting magnets developed to date. Much of the required effort involves design, fabrication, and testing of large hardware items, a process which is inherently time-consuming. Furthermore, experience has shown that long time spans are typically required to qualify new materials for complex large-scale engineering applications. The intermetallic compound Nb_3Sn, which like $YBa_2Cu_3O_7$ is a brittle superconductor, has been used for over 20 years in many magnets, both small and large, but an accelerator quality magnet has yet to be constructed. This experience provides additional confidence that the estimated development interval represents a lower limit to what is achievable under realistic conditions. It is important, however, to note that many less demanding high-field magnet applications exist which could be realized sooner.

I Introduction

This report contains the findings and conclusions of a study which was undertaken by the Basic Energy Sciences Advisory Committee (BESAC) at the request of Dr. A. W. Trivelpiece. In a letter dated April 23, 1987 (Attachment 1) Dr. Trivelpiece asked that an expert panel examine the possible utility of recently discovered high-temperature superconducting materials (e.g. yttrium barium cuprate oxides of nominal composition $YBa_2Cu_3O_7$ - often referred to as 1, 2, 3 compounds - which exhibit superconducting transition temperatures above 90K) for high-field magnet applications in particle physics. Specifically, he directed that the study focus on the Superconducting Super-Collider (SSC) magnets as a benchmark, and asked that the panel (a) review developments in the field of high T_c superconductivity and the materials requirements which would have to be satisfied, (b) assess the technical obstacles which would have to be overcome, and (c) provide considered judgment on the time scale for development.

The Panel was organized in June, 1987 and held three formal meetings: Washington, DC - July 7, 1987; Berkeley, CA (LBL) - September 14-15, 1987; Murray Hill, NJ (AT&T-BL) - October 23, 1987. (The meeting agendas are reproduced in Attachment 2.) In addition to the indicated membership three other members were appointed initially but were unable to participate because of unavoidable schedule conflicts (Prof. C. P. Flynn; Prof. T. H. Geballe; Dr. J. K. Hulm).

The Panel is indebted to the technical insights provided by Dr. J. W. Ekin (NBS), Dr. M. Tigner (LBL), Dr. A. T. Tollestrup (Fermilab) and Dr. K. Patel (AT&T-BL). Support provided by Dr. A. T. Aldred (Argonne) and the institutions who hosted the meetings is also gratefully acknowledged.

The main body of the report is organized as follows: Section II explores the materials requirements; Section III discusses the current status of high-T_c developments; Section IV defines milestones for a high-T_c magnet development program and discusses associated technical issues and time scales. Section V summarizes the Panel's principal conclusions.

II **Material Requirements**

The design of superconducting high-field dipole and quadrupole magnets for beam confinement in high-energy particle accelerators must satisfy considerably more stringent performance requirements than are typical for other magnet applications. To be practical, accelerator magnets must be capable of reproducibly generating strong fields of high uniformity ($\Delta H/H<10^{-4}$) over appreciable lengths and volumes along the beam tube. Field strengths must be variable over a wide range ($H \approx 1$-7T). Operational lifetimes may stretch beyond ten years, during which large numbers of thermal and field cycles (including accidental superconducting to normal state quenches) will occur. In addition, cost considerations related to the large circumference of an SSC-class accelerator dictate that the volume of conductor and support structures be minimized. The magnets therefore require small dimensions and thus very high current densities ($J>10^5$A/cm^2). The small dimensions, in turn, increase the demand for high winding accuracy and low persistent magnet currents.

The specific requirements for the benchmark Nb-Ti SSC dipole magnets currently under development can be summarized as follows:

(1) Magnet Dimensions and Current Density

The SSC dipole magnets consist of two concentric coils 17 meters long in a "cos Θ" configuration. The windings have a 4 cm inner (bore) diameter and an 8cm outer diameter. The beam-injection field strength is ∿0.25-0.5T and the field strength at maximum energy is 6.6T. The maximum current densities in the Nb-Ti superconductor are stated to be 1.3×10^5A/cm^2 and 1.8×10^5A/cm^2 for the inner and outer coils, respectively. The specified critical-current density is $J_c=2.75\times10^5$ A/cm^2 at 4.2K and 5T.

(2) Filament Diameter

The magnet conductors are composed of small-diameter filaments in order to assure field stability and uniformity in the presence of induced persistent currents. The uniformity requirement is particularly demanding. Because of incomplete flux penetration the superconducting filaments develop a transverse component of magnetization in the field of the magnet. Consequently, each conductor element acts as a dipole moment. The spatial distribution of these dipoles contributes a beam-destabilizing sextupole component to the central field which scales as the product of the filament diameter (d_f) and the critical-current density. The effect on beam stability is most serious at low fields, corresponding to beam injection. This dictates an upper limit of $d_f \approx 5$-10μm (For larger diameters correction coils to compensate for the field error become impractical.) This requirement rules out the possibility of constructing the magnets from simple tapes, as was done with many early Nb_3Sn laboratory magnets.

(3) Conductor Cable

The filaments are combined into multi-filament strands, which in turn are assembled into a cable capable of supporting a current in excess of 5,000A. A high current is desirable to minimize magnet inductance and quench voltage, and is therefore independent of the superconducting material used. The strands are twisted along the cable direction, with a pitch which is optimized to minimize ramp rate losses and field non-uniformities. Moreover, the rectangular cross-section of the cable and the distribution of conductors must be controlled within very small dimensional tolerances. Individual filaments and strands must remain sufficiently isolated to avoid error-producing magnetization supercurrents between adjacent conducting elements.

(4) Stabilizer

About 60% of the conductor cross-section is copper in intimate contact with the Nb-Ti filaments in order to ensure electromagnetic stabilization and thermal protection in the event of quenching.

(5) Mechanical Properties

The mechanical requirements are very stringent. High stresses and strains may occur during the heating and cooling processes necessary to form the superconducting cable, during coil winding, and during magnet energization. Experience with filamentary Nb_3Sn conductors has shown that the first two steps are more problematic than the third. Magnet conductors must be very precisely placed (to $\sim$0.02 - 0.05mm) in order to maintain field tolerances, and very high conductor packing densities are thus required. This demands tooling which applies large local winding loads during magnet assembly. Winding strains can locally exceed 1% unless special precautions are taken in the design. (For example, one Nb_3Sn dipole magnet design used expanded-radius end sections to minimize local bending.) Average cool down and electromagnetic stresses (of order 10ksi) are readily accommodated in the design, although stress concentrations at the end turns may well become limiting.

The material requirements for a magnet design based on a high-T_c superconductor are strongly dependent on the assumed operating parameters. The Panel adopted for its analysis field specifications identical to the baseline design, but with an operating temperature near 77K. [Refrigeration at 77K is more energy efficient than at 4K, and operation at the higher temperature might therefore result in capital and operating-cost savings. Actually, a detailed examination by the

SSC Central Design Group has indicated that the potential savings are small relative to total facility cost. The baseline design depends on helium cryopumping of the beam tube using the 4K magnet refrigerant. At 77K, the need for an alternate vacuum system (such as the non-evaporable getter technique) and the associated increase in magnet aperture would offset most of the savings. On the other hand, if the high-T_c superconductor could support substantially higher transport current densities, larger cost savings could be realized because of reduced magnet size. Alternatively, one could contemplate operating the new materials at 4K and higher field strengths in order to shrink the SSC ring circumference. This cost reduction strategy has not appeared attractive. The circumference only scales as H^{-1}, while the stored magnetic energy and hence the mechanical stresses scale as H^2. Accommodating these increased stresses in the structural design is likely to increase the total magnet cost more rapidly than the reduced tunnel circumference would provide in savings.]

Minimum values for the critical-current density and total current in a high-T_c magnet designed to achieve ∿7T are similar to the baseline specifications, since the same economic considerations apply here. The maximum filament diameter depends on the magnetization behavior of the high-T_c conductor over the specified current range at 77K. Although not known in detail at this time one can estimate that filament diameters of 5 - 10μm will again be required. Regarding high-T_c conductor stabilization, the relatively large heat capacity of materials at liquid-nitrogen temperatures compared to 4K will probably make electromagnetic stabilization unnecessary. However, thermal protection of the conductor during a quench is still required. Thus, normal metal of good electrical conductivity must be placed along and in contact with the superconductor. Consideration of the relevant materials constants at 77K suggests that the required cross-section ratio (normal metal:superconductor) will be equal to or greater than the baseline value of ∿1.5:1. Moreover, the larger heat capacity will result in very slow quench propagation and increase the requirements for active magnet protection. This would probably be accomplished by incorporating heaters in the body of the winding. The heaters may compete for space within the winding, increasing the requirement for conductor current density.

An indication of the relative difficulty of designing and fabricating superconducting accelerator magnets is found in the preferred use of ductile Nb-Ti alloys over the brittle intermetallic compound Nb_3Sn, despite the fact that Nb_3Sn has critical constants which are significantly larger. [Nb_3Sn:T_c=18K, $H_{c2} \gtrsim$ 21T (4.2K); Nb-Ti (47-50 wt% Ti):T_c=9K, $H_{c2} \gtrsim$ 11T (4.2K)]. Many small high-field solenoids, as well as some large-volume (3 meter diam.; 8T) magnets for fusion devices, have been constructed from Nb_3Sn. Attempts to fabricate dipole magnets, however, have required special techniques to avoid conductor damage in regions of small bending radius (end sections) and have been only partially successful. Some 20 years after its potential was first recognized no acceptable Nb_3Sn particle accelerator magnet has been demonstrated, despite several major Nb_3Sn dipole-magnet programs in the U.S. and abroad.

In summary, the requirements placed on a high-T_c superconductor operating at 77K for use in particle-physics accelerator magnets, such as the SSC dipoles, appear substantially the same as those for the low-temperature SSC baseline. The important requirements are (1) critical-current densities in excess of $2x10^5 A/cm^2$ in ~7T fields; (2) filamentary (~5-10μm diameter), normal-metal clad superconductors; (3) sufficient strength and toughness to assure conductor integrity during cable and magnet fabrication. Finally, it is essential that the conductor cable be manufacturable in adequate quantity and at acceptable cost.

III High-T_c Materials Development Status

Since the discovery of a new class of superconducting materials by Bednorz and Muller in early 1986, and the subsequent discovery that the related yttrium barium cuprate material ($YBa_2Cu_3O_7$) exhibits superconductivity above liquid-nitrogen temperature, an unprecedented research activity has been underway to explore the properties of this class of materials and to discover ways of processing them. The quantity of research findings already reported far exceeds the ability to concisely summarize all the interesting properties. This review is therefore restricted to those properties that play an important role in the design of high-field magnets.

(1) Measured Parameters

The availability of small single crystals and thin films of $YBa_2Cu_3O_7$ has enabled measurements to be made of a variety of superconductivity parameters. Representative results are summarized in Table I. The critical magnetic fields are single-crystal values obtained from magnetization measurements. A striking feature of the measured properties is the strong anisotropy in the critical fields. This anisotropy is in marked contrast to that of previous practical superconductors such as Nb-Ti and Nb_3Sn whose properties are essentially isotropic. Not included in Table I are results of recent experiments using muon spin resonance, polarized neutron reflection and small-angle neutron scattering designed to measure the magnetic field penetration depth (λ) since they are in disagreement with one another.

(2) Derived Parameters

The measured parameters yield low temperature ($T/T_c \lesssim 0.1$) estimates, using standard BCS and anisotropic Ginzburg-Landau formulas, of the coherence lengths (ξ), penetration depths (λ), and upper critical fields (H_{c2}) shown in Table II. Also listed are the local critical-current densities derived from H_{c1}, as well as an estimate of the mean-free path (ℓ).

The large magnitude of the Ginzburg-Landau parameters,

$$\kappa(H \parallel c) = \lambda^{(H \parallel c)}_{(a,b)} \; / \; \xi_{(a,b)}$$

$$\kappa(H \parallel a,b) = \left[\lambda^{(H \parallel a,b)}_{(a,b)} \; \lambda^{(H \parallel a,b)}_{(c)}\right]^{1/2} \quad \left[\xi_{(a,b)} \quad \xi_{(c)}\right]^{-1/2}$$

implies that yttrium barium cuprate is a strongly Type-II superconductor. The large anisotropy is indicative of the strong influence of the quasi-two-dimensional crystal structure on the superconducting properties of $YBa_2Cu_3O_7$. The rather small values relative to the unit cell dimensions derived for the coherence lengths parallel to and perpendicular to the Cu-O conducting plane (i.e., a,b plane) may well be of great importance in determining the critical currents in polycrystalline ceramics since they are commensurate with the "scale" or "width" of grain boundaries. Furthermore, local impurity segregation or other defects may occur on this scale, and would be expected to effect current transport.

(3) Critical-Current Density

The most important parameter for many practical applications is the critical-current density. Recent magnetization measurements on both epitaxial thin films and single crystals of yttrium barium cuprate indicate that the material can sustain local current densities of $\sim 10^6 A/cm^2$ at 77K and well in excess of $10^6 A/cm^2$ at 4.2K. In several cases these results have been validated in zero field by direct electrical transport measurements. These rather early values already compare favorably with the theoretical critical-current density (the so-called "depairing current density") at which the kinetic energy of the superconducting electrons equals the condensation energy $H^2/8\pi$. At 4.2K and 77K this theoretical limit is approximately $10^8 A/cm^2$ and $10^7 A/cm^2$, respectively.

In marked contrast to the thin-film results, the transport critical-current densities reported by groups all around the world for bulk ceramic and "wire" samples have until quite recently been much lower, typically less than $10^3 A/cm^2$ at 77K or 4K in zero applied magnetic field. Moreover, these relatively low values fall extremely rapidly when a magnetic field is applied. The reasons for the large disparity between the thin-film values and those of bulk ceramics have yet to be established with certainty. There is increasing evidence, however, that ceramics behave as granular superconductors, with some kind of "weak-link" or Josephson coupling between the grains. The importance of grain boundaries in determining electrical transport properties is demonstrated by the recent achievement of significantly increased critical-current densities in bulk materials in which an appreciable alignment of the crystallographic c axes was achieved. Critical current densities of $10^3 A/cm^2$ at 77K in applied fields of 1T were reported. However, some evidence suggests that weak-links may occur within grains.

(4) Mechanical Properties

Up to now the reported mechanical strengths of bulk samples of $YBa_2Cu_3O_7$ have been rather low (<10MPa). In each case, however, the samples have been quite porous, and it is likely that the measured strengths have been dominated by the presence of large flaws. A more realistic assessment of the attainable strength will have to await the availability of large numbers of fully-dense samples so that a statistically significant strength distribution (e.g. "Weibull" distribution) can be established.

Although in many magnet applications it is the strength of the superconducting material that enters into the design calculations, for brittle materials a more significant parameter is the fracture toughness (i.e., the resistance to crack propagation). Measurements on single crystals, by the indentation method, give a fracture toughness of approximately 1.1 ± 0.3 $MPa{\bullet}m^{\frac{1}{2}}$, a value somewhat higher than that of silicon ($0.7MPa{\bullet}m^{\frac{1}{2}}$) and of ordinary window glass ($0.81MPa{\bullet}m^{\frac{1}{2}}$). In many respects this single-crystal value represents a lower bound, since it should be possible to increase it by appropriate microstructural control such as by the incorporation of second phases or fibers (silver appears to be a suitable second phase). Nevertheless, since for flaws large compared to the scale of the microstructure the attainable strength is proportional to the fracture toughness and to the inverse square root of the critical flaw size, the achievement of high strength will depend on success in reducing the largest flaw size through processing. Assuming Griffith behavior and a minimum value of fracture toughness of $1.1MPa{\bullet}m^{\frac{1}{2}}$, the strength of $YBa_2Cu_3O_7$ ceramics is calculated to exceed ~100MPa if the flaw size does not exceed 100μm, and 300MPa if the flaw size is kept below 10μm. Thus, as with glass fibers and zirconia fibers, strengths of the order of 1GPa should be attainable by control of processing.

(5) Environmental Stability

Yttrium barium cuprate materials react with many common chemicals, including water. In the presence of water, $YBa_2Cu_3O_7$ decomposes to form barium carbonate, yttrium hydroxide and copper hydroxide or copper carbonate, depending on the pH of the water. The decomposition is particularly rapid for powders exposed to liquid water, but also occurs on exposure to atmospheric moisture, necessitating long-term protection if the material is to be exposed to air. The susceptibility to moisture is also manifest in the phenomenon of sub-critical crack growth observed even in single crystals. In this and other respects, $YBa_2Cu_3O_7$ bears a striking mechanical-property resemblance to ordinary window glass. The susceptibility to moisture attack and the attendant buildup of reaction products on the surface may also explain reported difficulties in making low-resistance electrical contacts to the material and to experimental difficulties encountered in tunneling and reflectance measurements.

The stoichiometric oxide is readily reduced by contact with reactive elemental metals such as copper. Since the superconducting properties of non-stoichiometric compositions $YBa_2Cu_3O_{7-x}$ are known to degrade rapidly for x>0.2, control of oxygen stoichiometry is vital. At present all synthesis routes require some time above ~850C to form the $YBa_2Cu_3O_{7-x}$ phase. At this point x lies in the range 0.3-0.5, and a subsequent oxygenation step at lower temperatures is required to reduce x below ~0.1. Any protective scheme must allow this oxygenation and also prevent the subsequent egress of oxygen during the operational service of the conductor.

The oxide is also reduced by contact with many common organic materials, such as acetone and hexane. Reduction also occurs when the powders are incorporated with a number of polymeric materials, including polyvinyl butyural, polyimide, silicone rubber and polyphosphazene. It is believed that these reductions arise primarily from the relatively easy mass transport in and out of the yttrium barium cuprate lattice and the known catalytic properties of perovskites containing rare-earth and iron-group cations. In some cases, the superconducting properties of the exposed material can be restored by prolonged heating in oxygen at elevated temperatures.

(6) Powder Preparation

The first samples of yttrium barium cuprate were prepared by the classical ceramic route of mixing powders of yttrium oxide, copper oxide and barium carbonate or hydroxide; the compound was formed during firing and subsequent densification. In the last few months, many workers have demonstrated that $YBa_2Cu_3O_7$ powders can be prepared by many other techniques, although problems must be overcome in almost every case before large-scale (>10kg) batches can be produced. A number of vendors already sell kilogram lots of fine powders (0.5-5.0μm) having the $YBa_2Cu_3O_7$ composition. Among the techniques found to be successful are: co-precipitation of hydroxides, co-precipitation of nitrates, the Pechini method, the amorphous nitrate route, sol-gel route using alkoxides, and metal-organic routes. Thus, there appear to be many alternative routes of powder preparation that must be explored.

(7) Thin Film Preparation

The first thin films of yttrium barium cuprate were produced by electron-beam evaporation of the metals from yttrium, barium and copper sources, followed by an oxidation step. Using the same approach, epitaxial thin films were subsequently produced on single crystals of strontium titanate. Since these initial successes, groups have reported that films can be prepared by a wide variety of standard thin-film deposition techniques, including planar magnetron sputtering, pulsed laser evaporation and molecular chemical vapor deposition. Also, epitaxial thin films have been grown on MgO, sapphire, cubic zirconia and barium fluoride. In addition, thick films (>100μm) have been prepared by plasma spraying and by sol-gel coating.

(8) Wires and Fibers

A number of groups have demonstrated techniques for making short lengths or strands of wire. The most straightforward is to extrude and then fire a mixture of yttrium barium cuprate powder and an organic binder. The smallest wire diameter produced in this manner is ~0.1mm. Although very simple, this approach is unlikely to produce long lengths of high-strength material because of the requirement to distribute uniformly and burn out evenly all of the binder. In a second approach, yttrium barium cuprate powder is compacted in a silver, platinum, gold or copper/nickel/gold tube, swaged or extruded down in diameter and then fired to sinter the oxide particles in the tube. The smallest diameter wire produced this way is reported to be ~0.2mm. A third method is to melt-spin a mixture of the constituent metals, followed by an oxidation step to form the compound. A fourth method, which is in some respects a variant of the previous one, is to spin or draw a molten oxide with a composition close to the desired $YBa_2Cu_3O_7$ and then anneal in an air or oxygen atmosphere. Compositions in the $YBa_2Cu_3O_{7-x}$ - CuO - $BaCuO_2$ phase field have to date been used for this process. It is also possible that fibers can be prepared by a number of chemical routes, in much the same way that fibers of superconducting lithium titanate have been formed from metal-organic precursors.

(9) Alternative Fabrication Routes

A number of alternative fabrication routes to the sintering or hot-processing approaches have been demonstrated, and each holds promise for particular applications. For example, it has been reported that $YBa_2Cu_2O_7$ in its tetragonal form can be superplastically deformed. Although strain-rate sensitivity and other superplastic forming parameters have yet to be described, the ability to deform the material superplastically offers the potential for forming the material into complex shapes. Other groups have shown that dense, textured material can be prepared sinter-forging and by hot extrusion. The alignment of grains produced by these two processes may confer some advantage on the attainable critical currents, but the extent of such improvement has yet to be ascertained.

A novel explosive forming method, potentially useful for bonding metals (and perhaps plastics) to $YBa_2Cu_3O_7$ and densifying it, has been demonstrated. This approach has been used to compact the oxide with copper powder, producing a variety of shapes of $YBa_2Cu_3O_7$ conductors in a copper matrix. The technique offers the possibility of intimately bonding the oxide/copper composite without chemical reaction at the interface.

(10) Alternative High T_c Materials

Tantalizing reports of superconductivity above 100K indicating the possible existence of materials having higher transition temperatures than $YBa_2Cu_3O_7$ continue to appear in the literature. Although no independent corroboration exists for these claims, it is not possible to rule out the existence of materials with significantly higher values of T_c. Most of these reports concern multiphase samples containing some $YBa_2Cu_3O_7$. The intense interest in higher T_c values continues to produce great activity in this field.

TABLE 1

Measured Parameters of Yttrium Barium Cuprate

T_c	91K
ρ(120K)	~400 $\mu\Omega$cm
n	4.2 x 10^{21}cm^{-3}

	H ‖ c	H ‖ a,b
dH_{c2}/dT $(T/T_c=1)$	0.6T/K	3.6T/K
H_{c1} $(T/T_c \sim 0.1)$	0.069T	0.012T

TABLE 2

Derived Parameters of Yttrium Barium Cuprate

ℓ	~1nm
$\xi_{(a,b)}$	3nm
$\xi_{(c)}$	0.5nm

	H ∥ c	H ∥ a,b
H_{c2}	35T	230T
$\lambda_{(a,b)}$	90nm	800nm
$\lambda_{(c)}$		90nm
κ	30	230
$J_{c(a,b)}$ $(H/H_{c1}=1)$	6×10^7A/cm^2	1×10^7A/cm^2
$J_{c(c)}$ $(H/H_{c1}=1)$		1×10^6A/cm^2

IV Development Milestones

From the findings in Section II it is apparent that the challenge of developing any new superconducting material for use in magnets such as the SSC dipoles is not limited to demonstrating adequate bulk properties. Materials science and engineering issues bear on all phases of magnet development including prototype construction and testing. In order to facilitate the identification of critical materials-related issues and bring confidence to the time-scale estimate the Panel divided the needed development task into a number of overlapping program phases and associated milestones.

Phase (0): Fundamental research
Phase (1): Demonstration of bulk material properties
Phase (2): Demonstration of filamentary superconductors
Phase (3): Demonstration of manufacturable cable
Phase (4): Demonstration of model magnets
Phase (5): Demonstration of accelerator-quality prototype magnets

It was assumed that the magnet conductors would be fabricated from a high-T_c material composition derived from $YBa_2Cu_3O_7$. The resulting conceptual program plan is shown in Figure 1. As defined here, Phase (5) would culminate in final prototypes equivalent to initial production magnets (i.e., full-scale production could commence at that time). In arriving at the 12-year development time the Panel assumed a level of effort comparable to that of the current SSC magnet program. Additional resources would increase the probability of success through parallel effort but would not necessarily compress the time scale significantly. Since the economic arguments for high-T_c particle-physics magnet applications are not compelling at this time, the actual development pace might be slower than assumed. The Panel recognizes that the discovery of materials having properties superior to those exhibited by $YBa_2Cu_3O_7$ and related ceramics might change that assessment in the future. Nonetheless, it is important to note that much of the required effort involves design, fabrication and testing of large hardware items, a process which is inherently time consuming and costly.

The specific tasks and issues associated with the individual program phases are described in the following:

Phase (0) Fundamental Research (indefinite duration)

This program phase addresses scientific challenges and opportunities. As a concurrent activity it plays two important roles in the present context. First, it provides supporting knowledge deemed essential for the rational development of any high-T_c superconducting-materials technology; and second, it offers a chance that a material far superior for high-field magnet applications than the known high-T_c oxides might be discovered.

The theoretical underpinnings of high-T_c superconductivity are still weak, and the fundamental limits to what may be achievable in the future are consequently unknown. A more complete understanding is needed to assist in the search for better materials, particularly those having higher critical temperatures, as well as improved chemical and mechanical properties. Topics requiring theoretical study include the nature of the pairing mechanism, the influence of crystal structure, and the influence of grain boundaries and lattice defects.

Phase (1) Material Properties (2 year duration)

This phase is concerned with developing material compositions and fabrication processes leading to an acceptable conductor material. Two critical milestones can be distinguished.

1.1 : Demonstration of bulk transport critical-current density $J_c > 10^5 A/cm^2$ in applied fields of ~7T in bulk samples.

1.2 : Demonstration of a prototype polycrystalline conductor satisfying required transport and mechanical properties.

The first milestone establishes adequacy of basic electrical transport properties; the second establishes feasibility of a small-diameter superconductor with acceptable electrical as well as mechanical properties.

The principal issues which need to be addressed in both cases are:

- Transport anisotropy (e.g. effect of preferential grain orientation in polycrystalline specimens)
- Superconducting weak links (conductivity across grain and twin boundaries; effect of impurities and strain)
- Flux pinning (identification and controlled introduction of pinning centers)
- Mechanical properties (fracture toughness; stability in stressed environment)

Phase (2) Filamentary Superconductor (3 years duration)

This phase addresses processing technology leading to a composite filamentary superconductor structure.

2 : Demonstration of adequate transport properties in a long, continuous conductor consisting of 5-10µm diameter superconducting filament(s) stabilized with a high-conductivity normal-metal cladding

Success at this stage of development will require much parallel exploratory effort involving numerous technical issues, such as:

- Fiber processing (precursor chemistry; fiber spinning; powder preparation/densification/annealing; control of preferential grain growth)
- In situ (matrix) processing versus independent clad-filament fabrication
- "Wind-and-react" versus "react-and-wind" trade offs (stress tolerance)
- Long-term chemical/physical stability of superconductor and of normal-metal/superconductor interface

Phase (3) Manufacturable Cable (4 year duration)

This phase develops the necessary multi-filament/multi-strand cable having the desired cross-section. Several intermediate milestones are envisioned before final cable demonstration:

3.1 : Fabrication of cable strand

- Process scale-up to significant billet size for in situ route, or combination of multiple filaments for build-up route.

3.2 : Testing of cable strand

- Acceptable $J_c(H)$ characteristics in long lengths
- Acceptably low magnetization currents (absence of proximity effects)
- Adequate stability protection (adequate normal-metal/superconductor contact)
- Adequate mechanical properties (resistance to compaction and bending stress)

3.3 : Optimization of cable strands

- **Correct any deficiencies based on earlier tests**

3.4 : Production of first cable

- Insulation and combination of multiple strands without strand damage
- "Cable-and-react" versus "react-and-cable" trade offs

3.5 : Testing of cable properties

3.6 : Demonstration of reoptimized cable

Phase (4) Model Magnets (4 year duration)

The object of this phase is to develop the necessary magnet technology, leading to successful demonstration of a full-size dipole magnet. The scheduled milestones are arranged to take maximum advantage of progress in the preceding phase as it occurs.

4.1 : Fabrication of small-scale solenoid from cable strands, and tests

- "React-and-wind" or "wind-and-react" of insulated strands
- Strand bonding
- Use of non-circular cross-section solenoids to simulate typical dipole strain distribution
- Quench survival at full design field

4.2 : Fabrication of short dipoles from preliminary cables

- Avoidance of winding damage for "react-and-wind"; or avoidance of insulation damage for "wind-and-react"
- Acceptably low magnetization

4.3 : Fabrication and test of short dipoles from optimized cables

- Cable survival on winding, or heat treatment after winding

4.4 : Demonstration of long dipoles from optimized cables

- Scale-up (tooling, quality control, length effects)

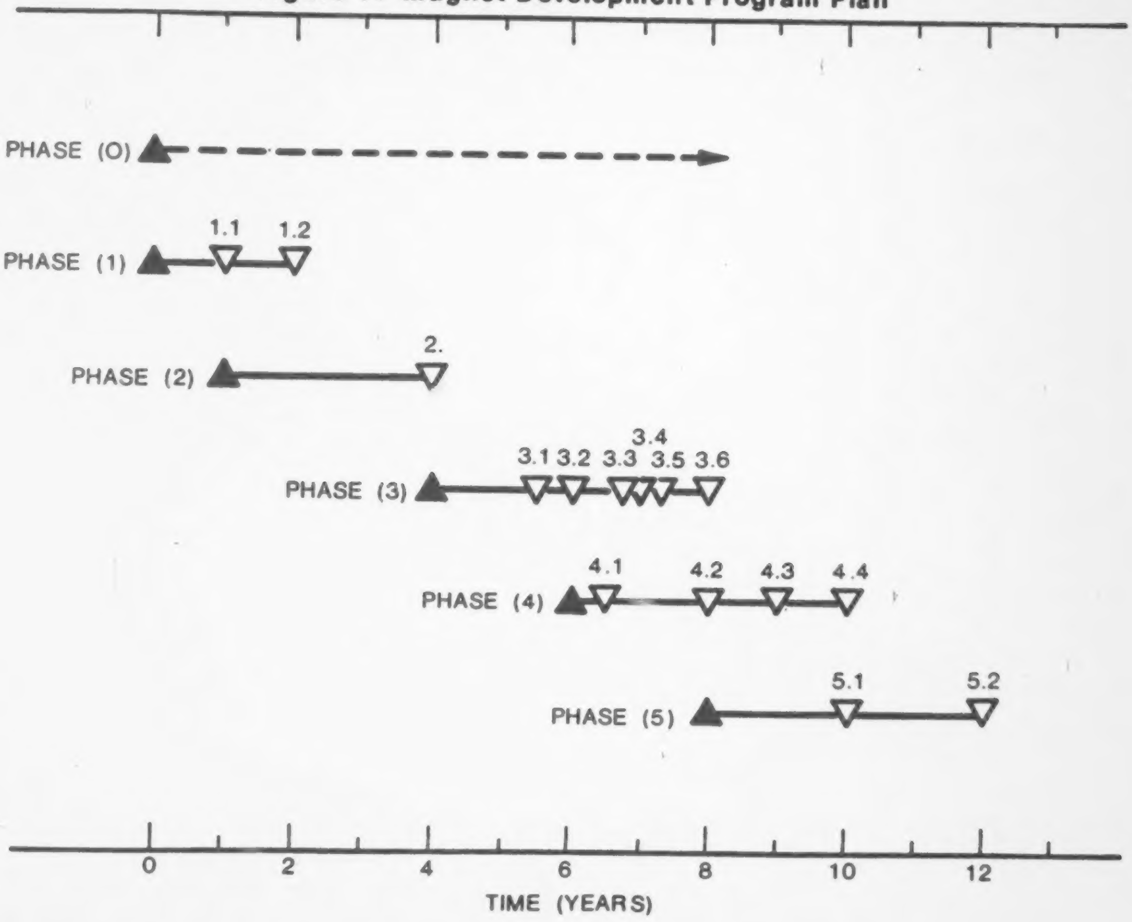
Phase (5) Prototype Magnets (4 year duration)

This phase accomplishes the necessary production engineering, culminating in the qualification of cable production and magnet winding for subsequent volume production. The objective is to assure controlled, reproducible processes yielding magnets capable of consistent generation of specified field strengths and quality without training or spontaneous quenches.

5.1 : Establishment and qualification of cable production capacity

5.2 : Demonstration of multiple coil production capacity

Figure 1. Magnet Development Program Plan



V Conclusions

A review of progress to date indicates that the intrinsic properties of $YBa_2Cu_3O_7$ are adequate, in principle, for high-field magnet applications at 77K. Nonetheless, formidable materials science and engineering problems will have to be overcome before feasibility can be firmly established for applications as demanding as those encountered in the design of the SSC dipole magnets. The development task cannot be eased by relaxing any of the critical magnet design specifications. Indeed, in certain respects the design of magnets for 77K operation may be more difficult. For example, the slower quench-propagation rate places greater demands on active thermal protection of the magnet winding. Although it is generally assumed without question that operation at 77K is more beneficial than at 4K, the actual design trade-offs can be quite complex.

The principal materials issues relate to the requirement for transport critical-current densities greater than $10^5 A/cm^2$ in a thermally stabilized superconducting filament of 5-10μm diameter in external fields of ~7T. Moreover, the filamentary conductors must be assembled into cables that can support currents in excess of 5,000A and survive the considerable mechanical stresses associated with magnet construction and operation. On the basis of rather optimistic assumptions, it appears possible to develop the necessary technology and demonstrate acceptable filamentary conductors in about 4 years. However, the Panel believes that under realistic conditions an additional 8 years would be needed before full-scale production of magnets equivalent to the SSC benchmark could commence. Two considerations add confidence that this conclusion is correct: (1) Qualifying new materials for complex large-scale engineering applications has traditionally been time consuming. (2) Although considerable effort has been expended to qualify Nb_3Sn for accelerator applications, the attempts have not been successful to date. The experience with Nb_3Sn is significant because this intermetallic compound shares the brittle characteristics of $YBa_2Cu_3O_7$.

As a final note, the Panel observes that many high-field magnet applications exist for which the requirements are less demanding and which could therefore prove practical much sooner. It is also possible that future materials advances, especially the discovery of materials having much higher T_c, would ease the design difficulty and also provide increased economic incentive for the magnet development program considered in the present study.

Department of Energy
Washington, DC 20585

Attachment 1

APR 23 1987

Dr. Robert Sproull
Chairman, Basic Energy Sciences
  Advisory Committee
201 Bausch and Lomb Hall
University of Rochester
Rochester, NY 14627

Dear Dr. Sproull:

I am writing to ask the Basic Energy Sciences Advisory Committee (BESAC) to undertake a study related to the recent discovery of superconductors capable of operating at liquid nitrogen temperatures and above. Although considerable excitement has been generated as a result of the new discoveries in high temperature superconductors, it is not known at this time whether and when the materials can be produced by manufacturers reliably, with appropriate properties, in a cost effective manner and in a suitable form for applications.

We would appreciate your putting together an expert panel to: (a) review the developments in high temperature superconductivity, together with the materials requirements to be met if these materials were to be used for magnetic field generation for particle physics, (b) assess the technical obstacles to be overcome in order for these materials to be developed and produced in quantity and with sufficient reliability to be used in construction of high field magnets for use in DOE's advanced research and development, and (c) provide us with your considered judgement on the time scale these developments might require. To focus your study, I suggest that you use the specific technical requirements of the SSC magnets as a benchmark for your analysis.

I know this is a difficult task considering the rapidity with which the science is developing and the extent of the extrapolations needed. However, the Department does need to understand the relevancy of these developments to the proposed SSC. I request that you try to provide us with a report by December, 1987.

Thank you for your assistance on this important matter.

Sincerely,

Original signed by
Alvin W. Trivelpiece

Alvin W. Trivelpiece
Director, Office of
  Energy Research

Attachment 2

Basic Energy Sciences Advisory Committee

Panel on High Temperature Superconductors

Agenda

Location: Hyatt Regency/Crystal City (at Washington National Airport) the Arlington Room (Phone: 703-486-1234)

July 7, 1987

Time	
9:00 am - 10:00 am	Panel Organization
10:00 am - 11:00 am	Dr. Jack Ekin, NBS (Measurements to date)
11:00 am - 12:00 Noon	Dr. Alvin Tollestrup, Fermilab (Magnet design and construction) Note: Dr. Tollestrup will be arriving in the morning from Fermilab and may need to be put on the agenda at a later time.
12:00 - 1:00 pm	LUNCH
1:00 pm - 5:00 pm	Panel discussion, next meeting
5:00 pm	Conclude

Attachment 2a

BESAC PANEL ON SUPERCONDUCTIVITY - MEETING #2

Lawrence Berkeley Laboratory
Director's Conference Room, Bldg. 50A-5132
September 14-15, 1987

Agenda

Monday, September 14

1:30 pm - Organizational Comments
Background Reports from Members

1:45 - Materials - latest results (Clarke)

2:15 - Theory (Reiter)

2:45 - Processing of NbTi, Nb_3Sn (Larbalestier)

3:15 - BREAK

3:30 - Magnet Technology (Montgomery)

4:00 - Ceramics Processing (Lange)

4:30 - Other Applications (Fradin)

5:00 - Discussion

5:30 - Adjourn

Tuesday, September 15

8:30 am - Discussion of Report Format

9:00 - Briefing on SSC Design (Tigner)

10:00 - BREAK

10:30 - Further Discussion of SSC Design

11:30 - Committee Discussion of Report

12:00 LUNCH

1:00 pm - Continue Discussion of Report

2:00 - Begin Writing Report

5:00 - Adjourn

Attachment 2b

Basic Energy Sciences Advisory Committee

Panel on High Temperature Superconductors

AGENDA

October 23, 1987 - AT&T Bell Laboratories - Murray Hill, New Jersey

8:30a.m.	Panel Discussion	
10:00	Dr. Kumar Patel	Research Results
10:30	Panel Discussion	

DISCUSSION

Mr. **Bruce**. First, thank you, Dr. Sproull. I am just curious about your comments about 10-year commitments and the ratio or the problems that you face with funding new starts versus sustaining funding for activities already in progress.

What should the ratio be? You indicated that a program ought to be at least it looks like 10 years in nature, that you ought to look toward a 10-year funding cycle. What should be the ratio if we obviously start all programs and didn't start any new ones, you wouldn't do any new starts for 10 years.

Dr. **Sproull**. Well, it's a rolling affair, of course, each year. If you have an average lifetime of 10 years and you get a chance to make changes at the rate of 10 percent per year, there's no science to this and there's very little art even. It's kind of a judgmental call as to what is good.

Those of us on the Committee have all served or are serving on the laboratory bench. In 10 years you can accomplish a great deal in a research program. You can take a year or two to get started and then you have, particulary if you have graduate students factored into it, kind of a lifetime of three years for a graduate student. In 10 years that program can bear a great deal of fruit.

Usually a faculty member himself or herself finds he gets a little bit of hybrid vigor by moving on to a different area of science anyway, perhaps coming to the Department of Energy for support again, but then it would be called a different program.

I can't claim any expertise is that that's just about right, but if it was much shorter than 10 years it wouldn't be an efficient use of money. If it's say 20 years, you would only have 5 percent of the money each year for new people or new programs and that would be a pretty static kind of program. So, I would just say that we looked into this and all of us agreed that that's a pretty sensible way to manage the peoples money.

Mr. **Bruce**. In this first year then, you are going to be stuck with a 90/10 ratio of 90 percent continuing and 10 percent new projects. We are talking a 3 percent growth in your budget in this area. Is that going to be adequate to meet the requirements, do you think?

Dr. **Sproull**. It is not. It certainly is not adequate. Unlike people that are in harness to the Government, I can say it straight out. That certainly is inadequate.

Mr. **Bruce**. You didn't read your statement line by line, and we also thank you for that. Can you give us any idea what you see from your Advisory Committee's perspective as an adequate increase in the budget this year as a percent of what you received last year?

Dr. **Sproull**. No, I can't. Look, if you are pushing as hard as you can, it isn't going to be enough. It's kind of fruitless to decide whether 20 percent or 50 percent should be applied. There has been a gradual starvation of basic research and basic research facilities over the last half dozen or a dozen years.

The real question is how much could you spend efficiently. Obviously, you don't just want to throw money at the problems. Probably, without adding a great deal of staff in the Department of Energy, you probably couldn't spend more than 20 or 30 percent additional efficiently. The chances of getting that are so slim that I wouldn't spend any time on trying to figure out whether it should be 20 or 30.

Mr. **Bruce**. Maybe you can help us in another area. I know that your Advisory Committee is new. Do you propose in the future years of your Advisory Committee with a set set of priorities, what programs we ought to fund?

Dr. **Sproull**. You have tasked us to do this and the Department has tasked us to do this, and it's the obvious thing that we ought to do. I just want to point out the disability of the committee and I don't want you to expect too much from us.

The problem is that in order to get technical competence over the tremendous range of science and engineering that the Basic Energy Sciences program sustains, like Noah's Ark we have to have one of these and one of the other and one of the other, and so on. We have, within the committee, spokespeople for just about every program there. Every one of those people thinks that his program is being starved.

You shouldn't really expect too much from a Committee like this, to be able to sit down and say where some programs ought to be cut in order that other programs could prosper at a faster rate. It's easy to say the latter. It's very difficult for a Committee like this to come up with anything useful for you in the former. So, we will do our best but don't expect very much.

Mr. **Bruce**. We will expect more. Noah wanted not one of these and one of those but he wanted two of these and two of those.

Dr. **Sproull**. There were certain biological problems.

Mr. **Bruce**. Right. We need to get them in two's. Mr. Morrison, do you have questions for the witness?

Mr. **Morrison**. Maybe that's what is wrong with the budget process. We've just had one of these and one of those. It hasn't been growing very well.

Let me start by saying on behalf of the Subcommittee, we really appreciate your service and others that work with you on the Advisory Committee. We have been criticized in the science and technology area Congressionally and perhaps appropriately, for a number of projects that have been started that really didn't lead us anywhere. As I indicated to Dr. Decker, I think we should be very pleased at what we see in the Basic Energy Sciences Program. I know that you are new on the job, but I am very confident the Advisory Committee can serve the necessary role of keeping this on track.

One of the greatest problems that we have on this Subcommittee is first about sorting out what you start, and sometimes even more difficult is when do you cut off something you have started and should be transferred into the private sector.

Have you established any guidelines for your committee on both initiating new activities and eliminating old ones within this average 10-year timeframe that you have discussed?

Dr. **Sproull**. Yes, but I don't think that they will surprise you. There is certainly no wisdom that we have contributed that the Department of Energy didn't already have.

One of the things that has been stopped is the older reactor facilities. As modern technology comes along, the older reactors have been decommissioned, which is perfectly sensible and that's the way it happens. Now, there are two other reasons why things get stopped. One is that they get stale and the people aren't productive anymore. Second, is that in a more or less constant money atmosphere, in order to start something new with high promise you have to stop something that's going on that although it's not poor science, it doesn't have the open endedness the new programs have.

This is done every year with several hundred projects, 50 or more are terminated for either one of those two reasons. Either the people have run out of steam or the good people have left the program and gone into other work or become over aged administrators like me, or because the work simply doesn't have the openendedness the scientific and technological promise that it had in competition with newer ones.

Those are the common reasons, they are good reasons, and it's up to the managers with the help they can get by voluntary unpaid advice from the technical community to put those into effect. We think they do it pretty well.

Mr. **Morrison**. Will the Advisory Committee play a role in new initiatives such as the Molecular Science Research Center that is being proposed?

Dr. **Sproull**. We haven't been asked to. I'm not sure how well we would do on that. I think we could do, for example, a thing like this Dr. Narath's high-temperature superconductivity task force, we could set that up. On the other hand, Dr. Decker's people could set up a task force just as well.

If we were asked to do that we would, I think, generate a group of people overlapping our membership somewhat but we would simply have to go outside of our membership in order to get deep enough competence. It might be useful; on the other hand, the people in Germantown may have better ways of going about it. I simply don't know.

Mr. **Morrison**. Thank you. We want to make sure what we do is right and we have confidence in your group. Thank you very much.

Mr. **Bruce**. Mr. Fawell.

Mr. **Fawell**. Thank you, Mr. Chairman. You had mentioned that sooner or later DOE, the Department of Energy will be blamed for the next energy crisis.

Dr. **Sproull**. That's a personal comment of mine. I suppose it's gratuitous and probably about as good as——

Mr. **Fawell**. It caught my fancy. In speeches that I have made in my District at least, perhaps we who are interested in the energy sciences don't do enough to pound our chests and say we aren't spending enough here. We aren't doing enough and we are not telling the story, and we are continuing to burn fossil fuels and do it the old way until such time as the last drop of oil is done and the last piece of coal——

This is maybe not a very good question and maybe an unfair one, but would such criticism be justified. I mean, who are we going to blame for the next energy crisis?

Dr. **Sproull**. I think Congress—first of all, there's going to be a lot of blame to go around. [Laughter.]

There's going to be plenty of blame. The Congress deserves some of it, the Administration deserves some of it, and we in the technical community deserve a great deal of it. There will be lots of blame. Each of us has our own little projects that we think are just great and we can give you some rhetoric to show you why they help to prevent another energy crisis. We can't tell you when they will come to fruition, and we can't tell you how they will lead to products and services.

On average, we know that there will be a certain amount of that that's true. There's a certain amount of risk in any basic research. On the average, it pays off. I think the likelihood that the press will go back and find people to blame is very high. They will point out that after a great amount of fanfare post-1973, most of those projects went up very fast and went down very fast and didn't contribute a lot to help avoid another energy crisis.

If basic research could be expanded now in the next few years, I'm sure it would be helpful. But there needs to be lot more looking into for example, the basic science of liquid hydrocarbons in the ground. There's not nearly enough work going on now on how to do secondary and tertiary recovery and how to deal with the oil fields and gas fields that are in America and ontiguous seas.

So there is just so many ideas going begging that could help mitigate a energy crisis in the future. It would be, I think, an excellent investment to do so. The problem that you face and that we face is that we can't predict when the crisis will occur, and we can't predict how long it would take for the basic research in things like the geophysics and geochemistry of hydrocarbons in the ground to make a payoff.

The industry itself can be counted on for some of that, but it's hard for a company—particularly with oil prices at $14.00 or $15.00 a barrel—it's hard for an American company to invest money when it has to have an internal rate of return of say 20 percent. It has to expect to get its return back in five years. It can't claim to its stockholders that it can do that.

Somebody has to take a longer view, and the only game in town for taking a longer view is the Federal Government.

Mr. **Fawell.** It's a difficult subject. We have talked about so many of the new energy sciences as not being anywhere near cost efficiency. When we take into account what it is going to cost us to repair the holes in the biosphere and all the damage that we are doing—I read a story the other day that in any major city that one can't get enough sunlight even by going out in the sunlight. You can't really get that which will manufacture Vitamin D, hence colon cancer and breast cancer are surging upwards.

When we stop and think how much it is really costing us to neglect all of these energy sciences, we might find that we passed the cost efficiency already. The only other point I had, you did also make a statement that the Department has created unique user facilities and this is a great success story.

I am going to go back to a user facility that is in the making which is the Advanced Photon Source which is being funded at $6 million this year. At the $400 million cost, it will take us 61 years to be able to complete that construction. That's obviously just not accurate, but did you look at that particular user facility and note the weak construction amount?

Dr. **Sproull.** Yes.

Mr. **Fawell**. If we continue to do that, I don't know if we will ever construct it.

Dr. **Sproull**. It's a great hangup. As I understand it, that facility probably won't come on line until April of 1996 and it may even slip beyond that. I am told that the Japanese will have a comparable facility a year earlier and that it will copy the Argonne technology. They work harder in Japan.

Mr. **Fawell**. They will start their construction later too, won't they?

Dr. **Sproull**. That's right. As I understand it, they have copied pretty nearly, line-for-line, the Argonne design. That's good and that's bad. It's good in that the U.S. is providing leadership of a technical sort for the world; it's bad in that it's helping our competitors to get a leg up on us.

I wish we could find some way or you could find some way of accelerating that, just as I would like to see the Advanced Neutron Source accelerated. There, too, I think the French will have at Grenoble, a source comparable a year or so earlier. It's awkward and disappointing when we are struggling for our technology advantage in world markets to be so slow on these facilities which are absolutely essential for anything we do.

For example, in high-temperature superconductivity, more and more the work shows that these fantastic materials rely upon a very intricate ordering and layering of the internal structure. Both the Argonne facility and the Oak Ridge facility will be extremely useful in sorting out and classifying and aiding the development of these materials. But they can't do it until they are on line, and it's going to be a long wait.

Mr. **Fawell**. Thank you very much.

Mr. **Bruce**. Mr. Walgren, did you have questions?

Mr. **Walgren**. No questions, Mr. Chairman. Thank you.

Mr. **Bruce**. Dr. Sproull, we are very happy to have you here. The work of your Committee and Dr. Monrton, who has accompanied you, I appreciate your comments. I caution you on your statement that on average we are doing a good job. Dean Rusk, Secretary of State was one time asked that. He said on average I think I'm doing a good job and the press said what does that mean. He said, if you had a man standing with one foot in the bucket of boiling water and the other foot in a bucket of ice water, that on average he would be comfortable.

So, on averages we can get in a lot of trouble. We think that you are doing a superior job, not just an average job.

Dr. **Sproull**. Your Committee must think that you have your feet in the boiling water. [Laughter.]

Mr. **Bruce**. That's right. Thank you, Dr. Sproull for the work and all the other members of the Advisory Committee. We certainly appreciate what you have done.

[Questions and answers for the record follow:]

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

Hearing on the Department of Energy (DOE)
FY 1989 Authorization Request for Supporting Research
and Technical Analysis

Republican Member Questions for the Record
for the Hearing of March 23, 1988, for
DR. ROBERT L. SPROULL, CHAIRMAN,
BASIC ENERGY SCIENCES ADVISORY COMMITTEE

1. Do you believe that the Basic Energy Sciences Advisory Committee (BESAC) is playing a useful role? Is the BES management listening to you?

2. You note at the end of your testimony that "the DOE FY 1989 Budget Request for BES (and BES-related facilities under BRUF) is far too modest." Do you have any specific funding recommendations?

3. What studies is BESAC likely to undertake this year?

(Response by Robert L. Sproull)
21 April 1988

1. Yes. BESAC is the only group advising the DoE and the Congress on the diverse but vital programs in Basic Energy Sciences. In addition to our oral counseling and written reports, we provide an informal coordinating mechanism by our visits to National Laboratories and by the work of our subcommittees.

Yes. Even our preliminary recommendations of last spring were treated seriously; DoE was naturally unable to respond immediately and literally to our recommendations about HFIR and superconductivity, since they did not have sufficient flexibility and had to take from other programs, but they moved in exactly the direction we advised and moved farther and faster than we could have expected. The line-by-line response by the Acting Director of Energy Research to our first annual report was wholly satisfactory to BESAC (which is hard to satisfy).

2. I am reluctant to make specific funding recommendations for the following reason: The BES budget already suffers from being what scientists call an "over-determined system"; by that is meant that there are more constraints on it than can be obeyed at the same time. I do not wish to add yet another constraint. An increase in appropriations would allow a more effective program, and an 15% to 20% increase could be managed very efficiently. If that is impossible, removal of some of the Congressional restraints would make for a better managed program and a more efficient use of the people's money. Additional support of the user facilities would permit around-the-clock and around-the-calendar operation, which would produce more research at lower cost per unit. Advancing the funding schedule of facilities planned or under construction would help us compete more effectively with the rapidly developing overseas facilities. More research funds are needed everywhere, but perhaps most urgently in materials, chemistry, and geosciences.

3. Our highest priority is to learn more about the individual programs and to begin to study the balance among programs. In addition we shall be studying facilies, especially planned new facilities, and their utilization. We shall be following closely the HFIR "get-well" program and the moves into high-temperature superconductivity. Since all members of BESAC have important and responsible jobs already and since BESAC service is an "add-on" without compensation to already busy schedules, there is a limit to what I can promise that we shall accomplish.

Robert L. Sproull

PANEL 1: DEPARTMENT OF ENERGY NATIONAL LABORATORIES

Mr. **BRUCE**. Our next panel will consist of Dr. Alexander Zucker, Acting Director of the Oak Ridge National Laboratory; Dr. Alan Schriesheim, Director of the Argonne National Laboratory; and, Dr. William Wiley, Director of the Pacific Northwest Laboratory. Gentlemen, welcome to the Subcommittee. We are certainly happy to have you here. We will start with Dr. Zucker and work right on down the table.

Dr. Zucker, if you would give your testimony please.

STATEMENT OF DR. ALEXANDER ZUCKER, ACTING DIRECTOR, OAK RIDGE NATIONAL LABORATORY, OAK RIDGE, TN

Dr. **ZUCKER**. Thank you very much, Mr. Chairman. I, too, would like to submit my written testimony for the record and just cover a few points.

Mr. **BRUCE**. Without objection.

Dr. **ZUCKER**. First, let me comment on the Basic Energy Sciences budget. I would say that it is probably the best we can get. I don't think it is adequate, but under the circumstances I think it's probably the best we can get. There is, however, one glaring fault that particularly affects the Oak Ridge National Laboratory, and that has to do with the funding of the Advanced Neutron Source.

Last year this Subcommittee provided $7.2 million for this program. The Congress eventually passed that, and we are now faced with an Administration request of $3.7 million. This is no way to design a complex large machine that will be a pre-eminent research tool in the world.

The reduction devastates a meticulously-planned engineering and design program, and if the funding goes up and down like a yoyo we will waste people and money, and actually spend more money in the end. To keep the project on track, we need $8.7 million, an addition to the $5 million to the Administration's request for fiscal year 1989. This is truly the minimum that will maintain the start of construction in fiscal year 1993.

It grieves me that I will have to skip the technical highlights in my report. I would like to ask you to read them. I normally derive much pleasure in describing the work we have done, but I have other things that we have to talk about.

Let me turn to the High Flux Isotope Reactor, and say that the Laboratory is grateful to this Committee for its support to get the HFIR restarted. Congress has provided the required funding and we have strong support to get it restarted both from the Department of Energy Headquarters and the Oak Ridge Operations staff.

We have done a number of things since last April. First of all, we have installed a completely new team to run the reactors last April. We have developed an analysis of the pressure vessel that assures us that we have a 10-year lifetime. This analysis has been validated by a number of external committees. We have performed a hydrostatic test of the pressure vessel at approximately twice the operating pressure, and found no problems with the vessel at all.

We have performed a Probabilistic Risk Assessment, a first for any reactor in the Department of Energy, which assures us through outside consultants that the risk to the community and to the staff of operating this reactor is minimal. We have done some seismic upgrading of the reactor, and in general, tightened up many aspects of its operation.

I would like to say that the loss to science has been formidable; that the suspension of operation of the HFIR along with the Class B reactors has seriously impacted a large number of scientific enterprises, something that we can ill afford.

As you know, the Oak Ridge National Laboratory has been in the forefront of technology transfer, and I would like to make a few comments before I close on global competitiveness and the role of National Laboratories in that arena. All of us are aware of the challenge to our commerce and to our economy by our inability to compete globally. This is particularly true and particularly hard to take in the sector that deals with high technology.

Again, there is plenty of blame to go around. Industry can be blamed, Government, the scientific and technical establishment, our educational establishment—there's no problem finding culprits.

I would like this afternoon, however, to be proactive and suggest ways that might reverse this process. First, I would like to digress. I would like to take us back to the colonial days in New England where each town, each settlement had developed a Commons. This was a substantial parcel of land used without charge by the town citizens to graze their cattle and sheep and cut wood for their housing and repair.

The Commons was central to the prosperity of New England agriculture. The land was carefully tended and it produced much good for all the people who were associated with it. Today, technology is essential for the country's prosperity very much as agriculture was in those days, in the standard of living of its people.

I would like to suggest then that we create a Technological Commons in DOE's National Laboratories where American industry can take advantage of what the American taxpayer has bought and what it is paying for. Industry would have to pay its way just as the colonial farmer had to buy his own cattle and sheep, but the use of the commons would be free.

Industry could freely draw on the equipment, multi-disciplinary expertise, and the infrastructure of the Laboratories. Just as the colonial farmer drove his cow home each evening, American concerns would take home patents and data from their use of the Laboratories and would keep the necessary rights to them.

Industrial consortia could, in many cases, leverage individual investments through cooperative arrangements. The Technological Commons, just as its colonial predecessor, does not take away property rights. On the contrary, it enriches all of its users and enables each to achieve what he could not possibly do with his own resources.

What needs to be done to further this kind of concept? First of all, I think that this Committee can help in establishing an explicit mission for the Department of Energy and for its Laboratories, an explicit mission to participate in our effort to be globally competitive.

The second point has to do with funding. Of course, the Congress can provide funds and the Congress can provide tax legislation that would make this concept happen more readily. But we have to remember that the Stevenson-Wydler Act provides half a percent of R&D money already in the Laboratories for this activity, and because the global competitiveness has become so much more of an issue since 1980 when the Stevenson-Wydler Act was passed, I would suggest that the percentage be increased from the half percent to 1 percent.

The Advisory Committee to the Department of Energy has reviewed the technology transfer programs at the Laboratories and has found that among other recommendations, that technology transfer must be planned for from the beginning of a number of research programs. I agree with that, but I would go further. I would require that a number of appropriate research programs be judged by how well they have planned for technology transfer and that this be part of the criteria for funding.

I would just finally conclude, then, that we can find a common purpose to exploit the Technological Commons. Between the government, the private sector, the Department of Energy Laboratories, expand their objectives beyond their present mission to serve this Technological Commons that will enable the United States to take advantage of all of its resources and a quest for a better place in global commerce and technology.

Thank you, Mr. Chairman.

[The prepared statement of Dr. Zucker follows:]

DOE FY 1989 BUDGET AUTHORIZATION

Alexander Zucker

Acting Director

Oak Ridge National Laboratory

Testimony Before the

Subcommittee on Energy Research and Development

Committee on Science, Space, and Technology

March 23, 1988

TESTIMONY
SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT
COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY
March 23, 1988

Good Afternoon. My name is Alexander Zucker. I am the Acting Director of the Oak Ridge National Laboratory. I am pleased and honored by your invitation to testify before the Subcommittee on Energy Research and Development. In your letter inviting me to testify, you ask me to address several specific questions and I do so in the order in which they were posed.

FY 1989 Budget

The FY 1989 budget for Basic Energy Sciences submitted by the administration is very tight but probably the best that can expected in these times of deficits and stringent budgeting. There is, however, in the proposed budget one glaring fault, and it happens to directly affect the Oak Ridge National Laboratory. As you know, we are in the process of performing R&D and engineering design studies for the Advanced Neutron Source (ANS). This is a meticulously planned and calculated process that will culminate with a request for a line item in 1992 and start of construction in 1993. Last year, this Subcommittee approved $7.2 million for the ANS design project, a sum that was in fact appropriated by the Congress. The Administration's request for FY 1989 includes $3.7 million for the ANS. This reduction would devastate our carefully planned program, would delay both the line item and start of construction, and would in the end cost the taxpayer more money. Research, development, and engineering for a large and complex project like the ANS cannot go up and down like a yo-yo without sacrificing effectiveness and wasting people and money. To keep the project on track requires $8.7 million; an addition of $5 million to the administration's request for FY 1989. This is truly the minimum amount that will maintain the start of construction date of FY 1993.

Technical Highlights

This past year has been an exciting and productive one for the Basic Energy Sciences and Nuclear Physics Programs at ORNL. In addition to our progress in the superconductor and semiconductor areas, there have been numerous other significant advancements. A brief sampler follows.

Our Chemical Sciences work has led to the discovery of a new system for solvent extraction, an important industrial process used, for example, to separate pharmaceuticals and industrial waste products. An oscillating electric field replaces conventional mechanical stirring leading to an increase in the efficiency of the extraction process by about a factor of ten and to a reduction in the energy required for the process by about a factor of 100 compared to conventional systems. In a separate development, our analytical instrumentation effort has had another outstanding success. A new barium titanate tuning element in a conventional dye laser has extended the range such that one measurement replaces 2,000 measurements.

A major thrust in our Atomic Physics Program continues to be the development of HISTRAP, the Heavy Ion Storage Ring for Atomic Physics. While seven such facilities are being built in Denmark, Sweden, Switzerland , West Germany, and Japan, the U.S. has not yet responded. This is all the more disturbing because heavy ion storage rings currently provide the only way to study aspects of atomic physics that not only have great fundamental significance, but are also crucial for the development of fusion technology and national defense technologies for nuclear weapons and X-ray lasers. ORNL will be requesting $14.9 million for construction of such a facility (HISTRAP) in FY 1990.

The robotics program in our Center for Engineering Systems Advanced Research (CESAR) program, funded by Engineering Science, has received one of the highest compliments in technology development - we are being copied by the Japanese. One of our latest developments is HERMIES IIB, a mobile robot capable of autonomous navigation through moving obstacles, and able to use its own intelligence to find and adjust knobs until meters read specified values. HERMIES IIB is one of the most computationally powerful robots in the world with onboard computing power equivalent to about 16 VAX processors.

This year our Mathematical Sciences program and The University of Tennessee are jointly sponsoring a Numerical Linear Algebra Year. During this period, leading scientists from all over the world gather in Oak Ridge for workshops on each of the major research areas in this important field. Linear algebra is used in solving problems in virtually every technical field because it frequently provides the best method of solving partial differential equations. With the evolution of faster computers and the associated efficient techniques to solve these complex systems of equations, areas of science and technology will be opened that have been inaccessible in the past.

Jointly sponsored research continues to provide enormous benefits. In our basic Materials Sciences program, ORNL has developed the capability to grow single crystals doped with radioactive ions. This capability was essential in a joint effort between ORNL and LLNL that led to the first successful promethium laser. This laser represents a significant advance for undersea and satellite communications.

The joining of the microwave technology in the Fusion Energy Program and the materials scientists in the Basic Sciences Programs and Conservation has led to the development of a new processing technique for ceramic materials. Using 28 GHz microwaves, it is possible to heat ceramics more uniformly and more rapidly than with radiant heat sources. With microwaves, high material densities can be achieved at temperatures several hundred degrees lower than in conventional processes. In addition, microwaves may remove one of the barriers for the fabrication of ceramic engine components - they allow heating of relatively large and complex shapes.

The focus of the ORNL programs in Nuclear Physics is the Holifield Heavy Ion Facility. The Holifield has the world's highest voltage tandem electrostatic accelerator and produces the widest range of projectile species of any facility in the world. In addition to serving an extremely active in-house research staff, the Holifield Facility operates as an International User Program. Each year we host about 150 scientists from over 80 institutions, including National and Government Laboratories, industries, foreign institutions and about 35 U.S.

Universities from 20 states. This comprises the largest user community of any heavy-ion facility in the United States. Since 1983, over 80 graduate students have performed thesis research at the Holifield.

High Flux Isotope Reactor and the Advanced Neutron Source

Turning now to your specific questions, First, I would like to thank the Subcommittee for its support on behalf of the re-start of the High Flux Isotope Reactor (HFIR). The HFIR shutdown has been a scientific disaster. It has stopped the western world's only supply of several transuranium elements with all that this implies for science, for national defense, and for the treatment of cancer and other diseases. It has also deprived this Country of a major materials research facility, and forced 200 users to seek out other facilities.

Very substantial progress has been made to restart the HFIR. (1) A careful analytical study, supported by external reviews, has concluded that a ten-year life extension for HFIR is achievable without major hardware modifications. (2) The first of planned annual hydrostatic pressure tests has been performed. The results of this test unequivocally assure safe operation of the reactor vessel at an operating pressure of 485 psi, reduced from the previous operating condition of 750 psi. (3) A Level 1 Probabilistic Risk Assessment has been completed for HFIR (the first for any DOE reactor) and has been very successful in assuring low-accident risk. (4) A seismic upgrade program has led to minor modifications assuring that the HFIR can withstand an earthquake with twice the acceleration of the original HFIR design values. (5) Operations assurance has been upgraded with a new training program and the addition of a fifth shift of operators to provide more time for training. These and other things we have done represent one of the most successful reactor upgrade programs and will meet and exceed the increased standards imposed on restart. Funding for HFIR is about $20 million this year and must continue at that level. I am sure that you are as pleased as we that in-depth analysis has shown that major line items for replacing the vessel and for seismic upgrade are not needed.

Consider now what still needs to be done. We have been very disappointed with the continued shutdown of our Category B reactors. Over the past year, the requirements for restart of these small research facilities have increased so that the conditions for their restart are comparable to those for HFIR. While we agree with the philosophy that great diligence is required for the operation of any reactor, the loss to the research programs has been very serious. This includes a significant loss in this Nation's ability to develop high-temperature superconducting materials and in the loss of a joint U.S.-Japan collaboration in radiation shielding experiments. At least one of the Class B reactors, the Oak Ridge Research Reactor, is now permanently out of operation.

ANS

We appreciate the Subcommittee's support of ORNL's efforts to make the Advanced Neutron Source (ANS) a reality through the design and construction of the best and safest research reactor in the world. Compared with the best today, the ILL in Grenoble, France, the ANS will provide an order of magnitude (factor of ten) increase in neutron intensity, approaching 10^{16} neutrons/cm^2/sec sec. The ANS will open whole new vistas of research through its capabilities for neutron scattering research, materials irradiations for radiation effects research, and production of special isotopes for medical, technological, and basic science applications. Applications of neutron scattering include determination of biological structures, elucidation of the mechanisms of superconductivity, and characterization of numerous materials properties, including essential R&D for our polymer industries. To make certain that the needs of all of these important areas are met, we have established a National Steering Committee, comprised of scientific leaders from the disciplines that use neutron scattering, from the isotopes production/user community, and from the radiation effects community, to review our development program and the design parameters. The ANS is designed to function as a National User Facility that will provide the neutrons and research facilities to support a user community of 1000 scientists from universities, industries, and other government laboratories.

In the past year, research and development leading toward a design for ANS has progressed substantially. We have adopted a new generation safety approach for the ANS. For the first time, Probabilistic Risk Assessment is being used in pre-conceptual design evaluation. Thus, the design for the reactor literally takes a "safety first" approach. The ANS will, of necessity, be a very high-performance neutron source. Toward this goal, we are very pleased with the result of a collaborative effort between ORNL and INEL. The ANS core will combine the best features of both our concepts: it will be a split core (INEL) and the fuel will be arranged in the involute design (ORNL). Due to the high flux, the cold neutron source in ANS must withstand much more nuclear heating than current designs. To overcome this problem, a new concept was developed with two cooling systems to split skin cooling and volumetric cooling. Safety concepts for ANS combine all the best known features of decay heat removal and multiple containments. ANS is benefiting from the intense new safety analysis for HFIR. All of this is very encouraging but the delays in the FY 1988 budget process have delayed the target start up date by one year to 1997. To maintain this schedule, FY 1989 funding of $8.7 million is needed. This leads to a 1992 line item request for design funding and construction funding in 1993.

High Temperature Superconductor Research

Since the discovery of new high temperature superconductor materials just over a year ago, research to learn more about these ceramics has started and grown at unprecedented rates all over the world. At ORNL we have over 20 scientists working on understanding and improving the quality of the superconductors and the processing techniques. As a world leader in ceramics research, I believe we will make significant contributions in the development and application of this important class of ceramics.

A major focus of our research program is the study of the mechanisms that limit the current carrying capacity of the high temperature superconductors. The requirement for many applications is a million amperes/cm^2 whereas we can now achieve only 1 to 10,000 amperes/cm^2, depending on the configuration. There is thus lots of room for improvement. This problem must be solved before many technological applications become feasible. During the past year, we have discovered that a thin layer at the grain boundaries has a different composition than the balance of the material. We suspect that this layer, although less than 50 angstroms thick, is a barrier to superconductivity and may be responsible for the low current carrying capacity. We are using two techniques in which we have exceptionally good equipment and research capability to observe and identify materials at the needed resolutions, Auger Microscopy and Atom Probe Field Ion Microscopy, to study this layer and to explore new processing techniques to eliminate it.

Processing is very important to the properties of the new superconductors and might well provide the key to increase the current carrying capacity. ORNL was the first facility to use chemical processing techniques to form the powders from which the superconductors are fabricated. We are examining several chemical techniques that can generate kilograms of superconductor powder in single batches with better purity control and more uniform particle sizes than are possible with the more common mechanical grinding procedures. In addition, we are coupling heat treatment and minor compositional variations with extensive material property evaluations to better understand the mechanisms of high temperature superconductivity and its limitations.

Much of the information required to understand the superconducting properties can be obtained only through characterization of large perfect single crystals. ORNL is one of only a few institutions that has been successful in growing crystals of sufficient size and quality to perform the needed evaluations.

ORNL was the first to observe that certain magnetic properties can coexist with superconductivity in the new superconductors. Ongoing studies by our scientists of the magnetic properties with neutron scattering, first at the Oak Ridge Research Reactor at ORNL and now at ILL in Grenoble, France, provide essential information for understanding these phenomena and how they relate to the operative mechanism for superconductivity.

One possible near-term application of high temperature superconductors is as thin film conductors in electronic circuitry in, for example, computers and sensors. In these applications superconductors would reduce the heating and transmission time losses. ORNL is actively researching both fabrication and processing procedures for thin films. Recent work has demonstrated that traditional techniques used for removing ion implantation damage generated in ion beam fabrication of electronic structures are not successful with superconductors. New techniques, such as rapid thermal processing, will be investigated to overcome this problem.

Cooperation and joint research characterize much of ORNL's efforts in the superconductor area. The chemists are working with the materials scientists who are working with the theorists. Our scientists are working with scientists from other national laboratories, the National Bureau of Standards, and seven universities. I think that the future is bright in this exciting frontier area.

X-Ray Lithography Initiative

Let me now address your quastion concerning X-ray Lithography. A major technological concern for manufacturing submicron integrated circuits (IC) using X-ray lithography techniques is not only the availability of X-ray sources such as synchrotrons but the availability of the equipment and technology required to fabricate low-defect, stable X-ray masks. At a recent workshop at the University of Wisconsin in July 1987, the IC Manufacturing working group identified the availability of X-ray masks as the greatest single obstacle to the development of an application of X-ray lithography to the high volume production of ICs.

X-ray masks are far more difficult to fabricate than those for optical lithography. The scale of the features is fractions of microns rather than tens of microns. The mask consists of a patterned metal absorber on a thin insulating membrane. The metal absorber must be adherent and have sharp, vertical walls of a uniform specified thickness that are formed with submicron precision. The insulating membrane must be highly transparent to X-rays, dimensionally stable, rugged enough to be handled frequently in production use, and, for some uses, transparent to visible light.

The research at ORNL is focused on developing and understanding advanced deposition and etching methods capable of producing X-ray mask structures with these properties. We are also collaborating with the semiconductor industry to develop specific processing equipment for manufacturing masks and other needed structures. In collaboration with researchers at IBM we are developing advanced microwave plasma processing techniques and equipment for the deposition and etching of insulator, metal, and semiconductor film structures. Related research is being carried out utilizing laser-assisted chemical vapor deposition for selective deposition of films and for developing new non-toxic precursor gasses in collaboration with researchers at Dow Chemical. A new technique, called ion beam deposition, has been developed for deposition of virtually any metal film on any substrate with high aspect ratios. Many of these ion beam and laser techniques are also suitable for mask repair of microscopic defects, another important problem in X-ray lithography. Much of this work utilizes and extends the ion beam, plasma, and laser processing techniques developed over the years at the ORNL Surface Modification And Characterization (SMAC) facility through funding from the Materials Sciences Division of BES.

As I discussed with you last year, ORNL has proposed consolidating these R&D activities into an Advanced Processing Science Center (APSC) consortium with the semiconductor industry. We believe there will be an increasing need in the U.S. for more advanced processing equipment, for new materials, and for new manufacturing methods as future semiconductor device structures become more complex and smaller. We would like to join forces with the U.S. semiconductor industry to focus the enormous expertise of the DOE national laboratories on this problem which is so pivotal for maintaining our competitive position in semiconductor manufacturing. This approach is being actively pursued with the Department of Energy, SEMATECH, the Semiconductor Research Corporation, the Department of Defense, and other national laboratories, and has received encouragement and support from the Congress in the past. We are working actively with all of these organizations to make sure that the world renowned scientific strength that DOE has built at ORNL, that this Subcommittee has so generously supported, and that many of you have seen during your visits to Oak Ridge, are used effectively in this Country's battle for the future of a vital industry.

Technology Transfer

ORNL places a great deal of importance on improvement of our Nation's competitiveness. We are extremely active in our efforts to transfer patents for our developments to American industries. We are hampered in those efforts by the current requirement that we, because we are operated by a large-for-profit organization, must seek an individual waiver for every patent that we wish to license. The time and effort required for each of these waivers is enormous; for most industrial organizations timing is of the greatest importance, a delay of even a few months can seriously impact a marketing strategy. Laboratories run by universities and not-for-profit organizations have a blanket waiver for all of their patents. The policy change required to grant ORNL a blanket waiver has been initiated by DOE. It is my understanding that the matter currently rests in OMB. I would appreciate any help that you can offer in speeding the OMB reviews so that we too can obtain this essential blanket waiver.

In spite of these difficulties, ORNL developed technologies have been the subject of 17 license agreements. These licenses represent in excess of $10 million of product sales. The nickel aluminides technology that I discussed with you about five years ago has been licensed to four major companies, including Armco, one of the largest U.S. Steel companies. Nickel aluminide has the unique property that it gets stronger as the temperature increases, making it ideal for many high-temperature applications. Armada Corporation, the leading U.S. manufacturer of electrical resistance heating elements, has entered an agreement not only because of these mechanical properties, but also because nickel aluminides are based largely on abundant and economic domestic resources. Cummins Engine has a license for applications of the aluminides in large diesel engines. Several other companies are interested in nickel aluminides, including another large basic materials manufacturer and a manufacturer of airplane fasteners.

Another ORNL success story is the development and transfer of a whisker-toughened ceramic composite material. This material is the subject of seven licenses for application in the manufacture of cutting tools and wear parts. The commercial impact has been significant - the United States is recapturing the ceramic cutting tool market, a $200 M/year enterprise, from Japan.

Last year, I discussed ORNL's efforts to establish the Ceramics Advanced Manufacturing Development and Engineering Center (CAMDEC) as an industrial consortium. We have been assisting in the initiation of industrial consortia to expedite the commercialization of technologies in areas of national importance. CAMDEC has been proposed as a consortium for U. S. ceramic processing companies. CAMDEC would provide industry with a financially leveraged investment through cost-sharing as well as through access to the facilities, equipment and people at ORNL. Unfortunately, inter-industry barriers are difficult to overcome. The advanced ceramic manufacturers are highly fragmented and diverse; they are struggling to find a common ground. In fact, only one major U.S. company has committed itself financially to CAMDEC. To overcome this problem, ORNL is working to promote CAMDEC as a vehicle to implement the Advanced Ceramics Initiative proposed by USACA, the United States Advanced Ceramic Association. The Advanced Ceramics Initiative is an attempt to define and develop processing techniques for advanced ceramics for applications as, for example, an engine component. On the whole, I am disappointed with the rate of progress of CAMDEC, but we are continuing with our effort and hope that with the support of USACA, the concept may still bear fruit. If it does come together, all agree that it will greatly enhance the U.S.. position in the vital field of ceramics.

We had a major success last year. Thirteen companies have joined the Thermomechanical Model Software Development Center to fund the development of user friendly and intelligent software for analyzing the stresses in refractory systems, such as furnace linings. The original models, developed by MIT for ORNL, are too complex for easy use by industrial engineers. The consortium will provide the funding to allow the software to be used and interpreted by engineers who are not necessarily experts in finite element analysis.

Several other consortia are on the horizon. One that I find especially promising is a proposed consortium to meet the needs of electric utilities. The effort of this consortium would be focussed on extending the useful life and improving the efficiency and reliability of aging facilities. Planned targets include design and development of the heat exchanger of the future and improved diagnostic methods for inspection and evaluation of existing facilities.

Technological Commons

The intersection between science and commerce has recently received much attention. Under the popular slogan of Global Competitiveness, U.S. posture, policy, and practice, in international commerce and especially in the high technology sector, has come under scrutiny. In brief, most comments state that this Country is good at inventing, good at basic research, but bad at bringing new ideas to market and thus enriching its population. The blame for the deplorable state of the balance of payments is usually placed on industry, but our science and technology, our government, and those who are charged with managing these sectors come in for their share of the blame. And, there is plenty of blame to go around. The U.S. has squandered its lead in high technology in the marketplace, even if it is still preeminent in R&D.

Obviously, no single recipe will cure the situation. First, we draw some measure of comfort that the issue has finally attained high visibility. Second, the solution to much of what is wrong probably lies in the business community, especially its planning and marketing components. I do not propose to deal with this aspect of the matter. Instead, I will examine how industry, and through it, the Nation, may benefit from the large sums that the Federal Government invests in science and technology, through research and development at the many research institutions it supports. I further particularize my argument by restricting it to the question: how can industry derive some competitive advantage by using DOE's national laboratories, by exploiting their unique facilities, taking advantage of their highly professional and capable people, and cooperating with their management that is now all too willing to work for this cause?

There are eight such multiprogram laboratories; three have principally weapons missions, the other five are principally engaged in energy-related R&D. They all share some common characteristics. All are multidisciplinary since their missions require coordinated research programs in many areas of science and engineering to accomplish their goals. Most of them have large unique research facilities; accelerators, reactors, or special research centers which are typically "user facilities" that are meant to be available to scientists from industry, universities, or other government laboratories. All the laboratories have attained very high standards and are recognized throughout the world for their excellence. Each of them has some attributes, some areas of expertise, where it is preeminent in the world. And finally each, within the constraints of its mission, is available and even eager to contribute to this Country's effort to regain its global competitive position.

I recognize that there are important roles that university based research and industry's own laboratories must play here. But, with very rare exceptions, these organizations are not multidisciplinary, do not have large or unique facilities on the scale of the national laboratories, and very few have the breadth of experience or the infrastructure of the national laboratories.

What can we do to make use of these laboratories to enhance our competitive position in high-technology commerce. I have several suggestions:

1. The mission of DOE and its laboratories should be formally expanded to include global competitiveness, that is to help American industries to become more competitive. This kind of work, if it is to be successful, can no longer be regarded as a byproduct, a chance happening. It must be formally recognized by DOE and by the Congress, it must receive appropriate resources, and the best talent, as well as a high order of management attention.

2. Funds can be provided or are even now available from a number of sources. They can be directly appropriated by the Congress, or the tax laws can be structured to make it attractive for industry to utilize the laboratories. The Stevenson-Wydler Act passed in 1980 provides that one-half percent of the R&D funds at each laboratory be spent for technology transfer activities. The situation has become more critical in

the past eight years, and I believe warrants an increase from one-half to one percent. Moreover, greater effort should be made to assure that this money is used purposefully and resourcefully.

3. The ERAB panel that recently dealt with this subject recommends that technology transfer activities be included in the planning and execution of appropriate projects from their inception. That is a good idea, but I would go further: technology transfer should be included as a criterion for funding some kinds of research and success and this endeavor should be a basis for renewed or expanded funding. Federal matching funds for a few industrial consortia could be quite effective in promoting industry-laboratory interactions.

We already know all too well that simplistic messages from laboratories to industry will not work to transfer technology: "We are a great laboratory, come and make use of us;" or "here is a great invention, why aren't you smart enough to take advantage of it;" or "don't bother us with mundane problems, with manufacturing or marketing, we only work on the cutting edge of technology." Not only must government laboratories by more responsive to industry, but, industry also must realize that times have changed. Industry must give up its "not invented here" prejudice, it too must invest in first-rate people to carry technology transfer forward, and it must explicitly recognize this activity as important and reward success with prestige and advancement in its organization.

What emerges from these arguments is the need for a change in the way business regards government and in the way government regards business.

Both must actively work together, as they never have in this Country, and as they do so effectively in some competing Nations. The call then is for nothing less than a culture change, when we all know that culture changes are notoriously slow and painful. What I am suggesting is a first step, a relatively simple step, for changes in our technological culture.

From colonial times well into the last century, towns in New England had what was known as a Commons or common land. This was a substantial parcel of land used without charge by the town's citizens to graze their cattle and to cut wood for house repair and construction. The Commons was central to the prosperity of the New England agricultural society; the land was therefore carefully tended.

The modern analogy is obvious. Today, technology is essential for the Country's prosperity and the standard of living of its people. Let us create a Technological Commons in DOE's national laboratories where American industry can take advantage of what the American taxpayer has bought and is paying for. Industry would have to pay its way just as the colonial farmer had to buy his own cattle and sheep. But, the use of the Commons would be free. Industry could freely draw on the equipment, multidisciplinary expertise, and infrastructure of the laboratories. And, just as the colonial farmer drove his cow home each evening, American concerns would take home patents and data from their use of the laboratories and would keep the necessary rights to them. Industrial consortia could, in many cases, leverage individual investments through cooperative arrangements, thus uniting American business to enhance its competitive posture. The Technological Commons, just as its colonial predecessor, does not take away property rights. On the contrary, it enriches all its users and enables each to achieve what he could not possibly do with his own resources. With determination and a common purpose on the part of government and the private sector, the Department of Energy laboratories can expand their objectives beyond their present mission to serve as Technological Commons that will enable the United States to take advantage of all of its resources in the quest for a better place in global commerce and technology.

Mr. **Bruce**. Thank you, Dr. Zucker. Next, we would like to hear from Dr. Alan Schriesheim, Director of the Argonne National Laboratory.

STATEMENT OF DR. ALAN SCHRIESHEIM, DIRECTOR, ARGONNE NATIONAL LABORATORY, ARGONNE, IL

Dr. **Schriesheim**. Thank you, Mr. Chairman. In my comments today I, too, will submit written testimony and skip through it. I will comment on the Basic Energy Sciences Program, but I also intend to comment on some of the other programs within the Laboratory because they, too, are important for the Nation.

The first program that I would like to comment on is one that is high up on the Laboratory's priority list and high up on DOE and the Administration's list, and that is the Advanced Photon Source, the 7-GEV Synchrotron. We are certainly pleased that there is the budget request in 1989 for the start of construction on the Synchrotron, $6 million for construction, we are also delighted.

Obviously, we were delighted to be chosen as the site for this facility and we are eager to get on with the job of building it. We feel that it is the crucial facility to maintain U.S. competitiveness in fields of basic research, industrial research and defense-related research. I can comment, in fact, on each one of those and there are comments in this written testimony that go into detail.

I might say parenthetically that that facility has been one of the most peer-reviewed facilities that I have ever been in contact with in my career. It is the highest priority facility for materials-related research. I would point out, however—and that's been mentioned earlier—that there is some reason for concern and that is the European and Japanese machines, both patterned after the Argonne machine, are scheduled for earlier completion. I have details in the written testimony, details on the Advanced Photon Source that I will not go into.

I might just point out though, that picking up two of the industrial implications, the competitive implications, I might say that the electronics industry will use beams from the Photon Source to develop better semiconductors and yes, the beams will also provide better and safer means for medical diagnoses.

We plan a biomedical complex at the Advanced Photon Source, and we plan a facility for real-time angiography. If any of you have had relations or yourselves that have gone through angiographic procedures, you know what an agony that can be. This will really be non-evasive—the ability for non-evasive angiography.

I also mention that the Europeans and the Japanese are moving ahead rapidly with machines similar to the Advanced Photon Source. They benefit from our designs. As mentioned earlier, there is an advantage and disadvantage. They have come over and seen what we are doing, they have taken the designs, they have meshed them into their own machines quickly. They have equally-high expectations about the industrial benefits of the research. They are certainly moving forward with very aggressive construction plans.

In specific, the 6-GEV machine in Europe is being supported by a consortium of governments and will be built at a laboratory in Grenoble. They have a contract with an architect/engineering group that has already been signed. Several components for the machine have been ordered, and the schedule is remarkably like the one that we originally proposed for the Advanced Photon Source; one year for prototype development and four and one-half years for actual construction. With ground breaking in early 1989, they can have that machine up and running.

The Japanese have not yet selected a site for their facility, an exact site, but their construction timetable is probably even shorter. They envision breaking ground in early 1990 and constructing their machine on a four and one-half year timetable.

Under the Administration's budget request for 1989 and the construction schedule filed with the budget report, we will not complete the facility until April 1996. As matters now stand, the United States, which has pioneered in this field, will fall behind and will not fall behind as a matter of accident. We will fall behind as a matter of planning. We are scheduled to fall behind.

An incremental allocation of $14 million for construction funds in fiscal year 1989 would put us on a construction schedule that would bring the Advanced Photon Source into operation two years earlier. Instead of being in operation in 1996, we would be in operation in 1994.

Obviously, depending upon inflation, it would cost us less totally to construct that machine on an accelerated construction schedule. Looking out and assuming some things about inflation, we would save about $26 million for the nation by being on the short construction. Most importantly, it would allow this country to maintain its competitive edge.

I would now like to turn to another BES program, and that's the program in high-temperature superconductors. The competition here is obviously intense. It is driven by the prospect for huge markets in electrical-energy systems, communications, and microelectronics. The Laboratory has been in the forefront. Other National Laboratories have major programs in that area. Again, I don't intend to get into the details because you have those in my written report.

But I do again want to comment on the budget. The budget submission provides $12 million for superconductivity R&D through the DOE programs in electrical-energy systems. Their 1988 level was $4 million. We estimate that the funds available to Basic Energy Sciences for superconductivity research will increase only slightly from about $15 million in 1988 to $16 million in 1989.

Considering the commercial importance of these new superconductors and the need to improve our understanding of the basic reaction mechanisms, I would urge the Committee to consider ways of increasing the budget, even though I understand all the budget problems. I can go through a whole litany of other countries that we are competing with. I will be glad to send you some papers that I have written on this subject.

I would like to turn very briefly to another program outside of Basic Energy Sciences, but a program that bears on our energy posture in the country, and that's our nuclear power program. We, as you know, have played a major role in the development of nuclear power since the founding of the lab. Last week you heard Dr. Charles Till, our Associate Laboratory Director for Engineering Research describe Argonne's progress on the Integral Fast Reactor, or IFR.

It is really a continuing success story that exemplifies the strengths in the Argonne National Laboratory that illustrates how technical progress can be made with a strong research team, and with access to unique facilities. I might point out, again referring back to this earlier discussion on our national energy situation, that an inherently safe reactor—which is what this is—supported, of course, through its research phases by the Federal Government has one value before something like Chernobyl and another value after Chernobyl. It is difficult to place a value on that, it's very important.

I am really pleased that this year's budget submission places the full support of the Department of Energy before the IFR program. In fact, they consider it to be the centerpiece of the Department's nuclear program. As Dr. Till testified earlier, we are continuing work on modifications of the Hot Fuel Examination Facility and large-scale examination for metallic fuels at the Argonne Laboratory for use of DOE's test facility, and the bulk of that work goes on at our Idaho operation. We have additional allocation of $6 million that would enable us to meet Argonne and DOE's objectives in this area. I am less happy about the implications of the budget request for other areas of energy technology. We have seen substantial cuts in the budget for fossil energy, conservation, renewable, and those will cripple many promising R&D efforts.

We are still a long way from domestic fuel use technologies that can put an acceptable lid on future oil price shocks. I hope that the recent softness in the oil prices doesn't lull us into false complacency. I am afraid it has. I would like to see those budgets go up.

I want to end my testimony by commenting again briefly on technological transfer, something that Dr. Zucker discussed. We are quite pleased with the changes that Congress has made in the laws that enable the Laboratories to transfer technology more effectively and more quicker.

I would like to mention one of the Basic Energy Science programs at the Laboratory. We had invented a low-temperature refrigerator or so-called helium dilution refrigerator for one of our Basic Energy Sciences programs. A manufacturer in Tucson, Arizona saw that helium dilution refrigerator, he approached the laboratory—actually approached the corporation. We have set up with the University of Chicago, our contractor, and the ARCH Corporation.

Within five weeks, we licensed that technology to a manufacturer in Arizona. He is in the process of manufacturing that, and we will get some licensing.

Second, an advanced fuel cell that is under development at the Laboratory. We have recently cut a deal, if you will, with Allied Signal and Combustion Engineering to undertake a joint program with these two organizations. Allied Signal, Combustion Engineering and Argonne Laboratory, to commercial a fuel cell that we have been working on within the Laboratory. We are exploiting the spinoff and it has really been excellent for the Laboratory.

Finally, I want to compliment the Department for its university programs. We have one of the largest university outreach programs. Many of the laboratories have outreach programs. I might just mention that we are now completing arrangements—Mr. Chairman, you had mentioned the reactor program—we are completing arrangements for an important leaf in that reactor program.

We have been working between DOE and NSF on a jointly-conducted work for faculty and students at our related facilities. I believe that will be important for the nation. In addition, we have joined with several universities in the region, University of Chicago, University of Illinois, Northwestern University, to propose an S&T Center, Science and Technology Research Center in superconductivity.

I would like to close my testimony with what is obviously a self-serving statement, that is, that I consider these National Laboratories to be priceless, really. You couldn't pay for them. They are a priceless leaf in the Nation's portfolio and people within the Laboratories are, of course, really an asset, a national asset. I know that you consider that also. I thank you very much for the support you have given us.

[The prepared statement of Dr. Schriesheim follows:]

Testimony Before the

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT OF THE HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

by

Alan Schriesheim
Director of Argonne National Laboratory

March 23, 1988

Madam Chairman and Members of the Subcommittee, I am Alan Schriesheim, Director of Argonne National Laboratory. I am pleased to have this opportunity to testify today on the budget submission for the Department of Energy for FY 1988.

Argonne is a large multiprogram laboratory, operated by the University of Chicago for the Department of Energy. Of our 3700 employees, about 1400 are research scientists and engineers. Our facilities are located at two sites -- one near Chicago, Illinois, the other near Idaho Falls in Eastern Idaho. We have strong programs in both basic research and advanced energy technology.

In my comments today, I discuss the budget submission and its implications for several of our major programs. I focus on the Advanced Photon Source, research on the new superconducting materials, and our progress on the Integral Fast Reactor. I then describe some of our outreach activities, including work with the university community and technology transfer and educational programs.

7-GeV ADVANCED PHOTON SOURCE

Madam Chairman, we are pleased that the budget request for Fiscal Year 1989 includes funds for starting construction of the Advanced Photon Source. We were delighted to be chosen the site for this facility, and now we are eager to get on with the job of constructing it. This advanced facility will be crucial for maintaining U.S. competitiveness in many fields of basic, industrial, and defense-related research. Several national panels have designated the Advanced Photon Source to be the highest-priority facility for materials-related research. I would point out, however, that there is reason for concern. European and Japanese machines, patterned after the APS, are scheduled for earlier completion.

Most of us, when we think about facilities for producing x-rays, think about the machines that physicians use. The invisible rays from these machines pass thorough our bodies and, projected onto photosensitive film, they produce pictures of bones and internal organs. The important role that x-rays have played in the development of science and technology is less widely appreciated. For example, in the early 1950s, x-ray diffraction techniques provided the critical data that led Watson and Crick to their double-helix model of DNA. More recently, x-ray methods, combined with neutron scattering, have enabled us to determine the structures of new superconductors.

Conventional methods of producing x-rays for medical diagnosis -- and even for most scientific work -- are based on the same principles as the original x-ray tubes of Roentgen and Coolidge. Electrons are "boiled off" a hot filament and directed onto a target. Their deceleration and excitation of the atoms in the target causes emission of the x-rays.

Recent scientific applications of x-rays have put a premium on a property called "brilliance." High brilliance requires that many x-rays emerge from a point-like source, flow in a pencil-like beam, and have nearly the same wavelength. Remarkably, several recent advances in accelerator technology have made possible x-ray sources with just these properties -- sources that are more like lasers than like flood lamps.

The key is to use synchrotron radiation -- once regarded the waste product of particle accelerators -- as the source of the x-rays. By using storage rings to hold particles in orbit for long periods of time, and passing these particles through specially designed magnetic devices, we can produce x-ray beams of unprecedented brilliance. Incredible as it may sound, the APS will produce x-ray beams that are 100 billion times more brilliant than those produced by the best x-ray tubes and 10,000 times more brilliant than those from existing synchrotron-radiation sources. Moreover, x-ray beams at the APS will be tunable up to higher synchrotron-radiation energies than ever before achieved.

The multitude of uses of x-ray beams at the APS is truly extraordinary. Detailed studies of the structures and properties of materials promise development of improved alloys, ceramics, and polymers. Researchers from the petroleum, chemical, and pharmaceutical industries will be able to examine chemical and biochemical processes in unprecedented detail, allowing development of new drugs, chemicals, and catalysts. The electronics industry will use beams from the APS to develop better semiconductors. And, yes, the beams will also provide better and safer means for medical diagnoses. At the APS biomedical complex, we plan a facility for real-time angiography that will eliminate the risks associated with today's invasive procedures.

As I already mentioned, the Europeans and the Japanese are moving ahead rapidly on machines similar to the APS. Benefitting from Argonne's early conceptual design for the APS, and having equally high expectations about the industrial benefits of the research, they are moving forward with very aggressive construction plans.

The 6-GeV European machine is being supported by a consortium of governments. It will be built at a laboratory in Grenoble, France. A contract with an architect-engineering group has already been signed, and several components for the machine have been ordered. The schedule is remarkably like the one originally proposed for the APS -- one year for prototype development and 4 1/2 years for actual construction. With ground-breaking in early 1989, the Grenoble machine will come on line in mid 1993.

The Japanese have not yet selected a site for their facility, but their construction timetable may be shorter. (Not surprisingly, the Japanese are proving to be very good at accelerator technology.) They envision breaking ground in early 1990 and constructing their machine within a 4 1/2-year period.

Under the Administration's budget request for FY 1989 and the construction schedule filed with the budget report, Argonne's Advanced Photon Source will not be completed until 1996. As matters now stand, the United States -- which pioneered in development of these new x-ray sources -- is in danger of falling behind. More to the point, we are scheduled to fall behind. I urge that the Committee review this situation.

An incremental allocation of $14 million of construction funds in Fiscal Year 1989 would put us on a construction schedule that would bring the APS into operation two years earlier than now planned. The shorter schedule would reduce construction costs by $26 million. More importantly, it would allow us to start the U.S. research program two years earlier and keep us competitive in the many fields of science and technology that depend on the APS.

I now turn to the laboratory's work on the new high temperature superconductors.

HIGH TEMPERATURE SUPERCONDUCTIVITY

Discovery of the new class of high-temperature superconductors has set off an international race to exploit the technological potential of these materials. The competition is intense. It is driven by the prospect of huge markets in electrical energy systems, communications, and microelectronics.

Argonne has been at the forefront of superconductivity research. The pioneering structural work by Jorgensen and co-workers last year earned them the DOE Award for Outstanding Research in Condensed Matter physics. Their discoveries of copper-oxide chains and "puckered" planes were made using powder-neutron-diffraction facilities at our Intense Pulsed Neutron Source. These facilities are generally regarded as the best in the world. Other fundamental work at the Laboratory covers a broad range of investigations into the synthesis, characterization, and theory of the new superconductors.

Argonne is also pioneering in development of processes for fabricating the new materials into forms that can be used in the manufacture of devices and systems. You may have seen or read about our superconducting motor. Our commitment in these areas was reinforced when President Reagan designated the Laboratory as the Center for Superconductivity Applications. We are investigating and developing many fabrication techniques -- ceramic processing, chemical vapor deposition, ion sputtering, and spray processing, to name a few.

The budget submission provides $12 million for superconductivity R&D through DOE's programs in Electric Energy Systems. The 1988 level was $4 million. We estimate that the funds available to Basic Energy Sciences for superconductivity research will increase slightly -- from about $15 million in FY 1988 to $16 million in FY 1989. Considering the commercial importance of the new superconductors and the need to improve our understanding of their basic properties and mechanisms, I would urge the Committee to increase further the budgets for superconductivity R&D for FY 1989.

I now describe progress on our largest energy technology program -- the Integral Fast Reactor.

INTEGRAL FAST REACTOR

As you know, Argonne has played a major role in the development of nuclear power since the founding of the Laboratory. Last week you heard Dr. Charles Till, Argonne's Associate Laboratory Director for Engineering Research, describe our progress on the Integral Fast Reactor, or IFR. We at Argonne take particular pride in the IFR. We view it as a continuing success story. It exemplifies the strengths inherent in national laboratories and it illustrates how technical progress can be made when a strong research team, with access to unique facilities, focuses its energies on developing an exciting new technology.

The key features of the IFR -- metal fuel, liquid-metal cooling, pool-type design, and integral fuel processing and fabrication -- promise to revolutionize reactor technology. In the short span of four years, the IFR has moved from a small, internal Argonne study to its present position as the central project within DOE's advanced reactor program. The rapid progress has generated interest not only in the United States but also abroad, particularly in Japan and the Soviet Union.

Over the past year, our progress has been outstanding. IFR fuel passed 14.5 percent burnup in our Experimental Breeder Reactor-II, and fuel deposits in excess of 10 kilograms -- almost full-plant scale -- have been achieved in our electrorefiner. We also completed the Preliminary Safety Analysis for modifying the Hot Fuel Examination Facility/South, where we will demonstrate plant-scale reprocessing and fabrication. Equally important, tests of the transient response of the IFR fuel have confirmed the large safety margins that we had earlier estimated. In short, the IFR continues to meet our high expectations. We are particularly encouraged, by its economics, which remain exceptionally attractive.

I am very pleased that this year's budget submission places the full support of the Department of Energy behind the IFR program. As Dr. Till testified, the two biggest items for FY 1989 are continued work on modifications of the Hot Fuel Examination Facility and large-scale manufacture of the new metallic fuels for use at DOE's Fast Flux Test Facility. An additional allocation of $6 million would enable us to meet Argonne and DOE's objectives in these areas.

FOSSIL ENERGY, CONSERVATION AND RENEWABLE TECHNOLOGIES

I am less sanguine about the implications of the budget request for other areas of energy technology. Substantial cuts in the budgets of the fossil energy, conservation and renewable programs will cripple many promising R&D efforts.

At Argonne, proposed reductions in the R&D budget for fossil energy would severely impact the Laboratory's work in areas such as evaluation of metallic and non-metallic components for advanced coal technologies; continued development of advanced concepts for nitrogen-oxide and sulfur-oxide emission control; new methods for disposing of hazardous and toxic wastes; and basic studies on heat transfer and multiphase flow.

The nation is still a long way from domestic-fuel and advanced end-use technologies that can put an acceptable lid on future oil-price shocks. I hope that the recent softness in oil prices does not lull us into false complacency about the seriousness of the long-run problem.

Let me now turn to our outreach activities.

TECHNOLOGY TRANSFER

Argonne inventions are moving to market more quickly than in earlier years, because of enlightened Congressional legislation, new administrative procedures at the Department of Energy, new organizations at Argonne -- and much hard work by individuals now given appropriate opportunities and incentives. The two key organizations at Argonne are its Technology Transfer Center and an independently managed not-for-profit corporation called ARCH, founded jointly by Argonne and its operator, the University of Chicago. The University has dedicated income from part of its endowment to help support the operation of ARCH.

In FY 1987 the Technology Transfer Center formally screened 102 Invention Reports submitted by Argonne researchers -- a record number. ARCH also entered into its first licensing agreements last year. One of the licenses was granted to Research and Manufacturing Corporation of Tucson, Arizona, which will manufacture a helium dilution refrigerator developed at Argonne that is capable of cooling materials nearly to absolute zero. In another licensing arrangement, a firm established by a former Argonne employee will manufacture and sell a toxic gas detector.

An advanced fuel cell under development at Argonne is still some distance from commercialization, but its potential is so great that we have already concluded arrangements for joint research with Allied Signal and Combustion Engineering. This device could replace a conventional internal-combustion engine, achieving an 80 percent reduction in weight, much greater fuel efficiency, and the ability to use many different liquid and gaseous fuels.

Exploiting an important spin-off from our fission reactor program, Argonne engineers are preparing to adapt a powerful computer code called COMMIX for use as a design tool in the metal-casting industry. COMMIX had been developed to describe fluid flow and temperatures in the cooling systems of nuclear reactors. Lester B. Knight and Associates is working with Argonne to set up an industry consortium to fund further development of the code.

I could give you many other examples of Argonne technologies being transferred to the private sector. However, the point I want to make is that the institutions we have painstakingly established during the past three years to expedite this transfer are beginning to prove their worth. I am very enthusiastic and encouraged by their early successes.

UNIVERSITY AND EDUCATIONAL PROGRAMS

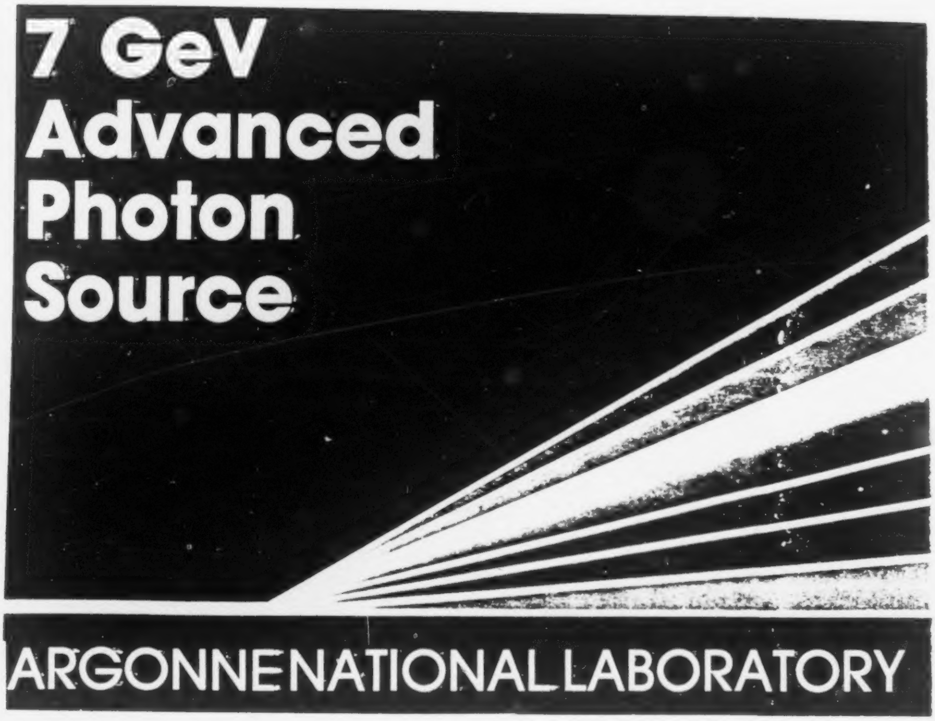
Argonne's cooperation with academia is extensive and productive. These activities are so diverse that often their full extent and importance are not appreciated. The laboratory conducts many educational programs for undergraduates, pre-college students, and their teachers. Argonne staff collaborate on research with university faculty and their graduate students. Our research facilities serve many university faculty from across the nation. Altogether, such diverse programs bring to the laboratory each year more than 2,000 teachers, students, and researchers.

The Laboratory's two largest accelerator-based facilities are the Argonne Tandem Linear Accelerator System and the Intense Pulsed Neutron Source. Along with our Electron Microscopy Center and other facilities, they bring to Argonne each year over 400 users from academia. Users of our Advanced Computing Research Facility -- numbering over 300 -- do not even have to visit us in person. They can link up remotely to the Center's seven advanced parallel computers.

Several of our new programs with the university community would entail participation and support by the National Science Foundation. We are just now completing arrangements for an important initiative in reactor engineering. Under terms of the memorandum of understanding, NSF-supported faculty and students will conduct research at our fission-reactor facilities. In a major initiative in superconductivity research, Argonne has joined with several universities in our region -- the University of Illinois, Northwestern University, and The University of Chicago -- to propose a Science and Technology Research Center. The Center would bring together an extraordinary array of research talent and facilities for a coordinated attack on technical problems underlying development of the new superconductors.

Recent studies have documented the decline in numbers of young U.S. students choosing careers in research. To help overcome this problem, the Department of Energy has developed an outreach program, the Science and Engineering Research Semester Program (an informative, if not a catchy title) to engage undergraduates in research at contractor facilities. Argonne has enrolled more students in this program than any other national laboratory.

Madam Chairman, as you well appreciate, the national laboratory system is a priceless leaf in the nation's science and technology portfolio. The laboratories represent an investment which the nation has made, makes today, and, I trust, will continue to make in the future. The returns from this enterprise have been extraordinary. As director of one of these laboratories, and as a taxpayer, I urge the Members of the Subcommittee to continue their strong support.

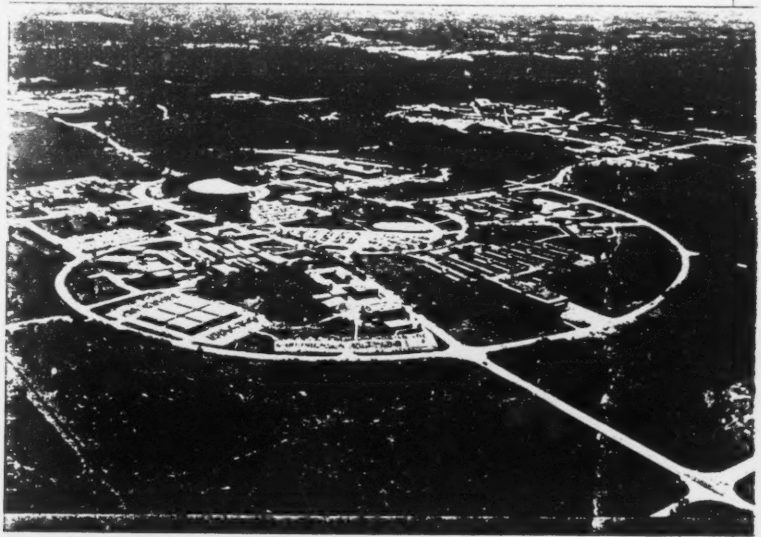

7 GeV
Advanced
Photon
Source
ARGONNE NATIONAL LABORATORY

7 GeV Advanced Photon Source

Argonne Director Alan Schriesheim

Argonne's 7 GeV Advanced Photon Source will provide a crucially needed national user facility for cutting edge research in the structure of matter. Scientists from industry, colleges and universities, and the national laboratories will use the unique properties of its x-rays to advance the frontiers of research in physics, chemistry, biology, and the materials and health sciences. This national resource will play a vital role in maintaining America's international technological leadership.

Argonne National Laboratory is one of the U.S. Department of Energy's largest multidisciplinary research centers. Argonne's primary missions are to perform engineering research in advanced energy technologies, and basic scientific research in the physical, biological, and environmental sciences. In addition, Argonne develops, builds, and operates major one-of-a-kind research facilities for researchers from across the nation.



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World's brightest x-ray source

Advanced Photon Source will pioneer research in many fields

Argonne National Laboratory's 7 GeV Advanced Photon Source, or APS, will use recently developed technology to produce the brightest beam of high-energy x-rays ever available for research — 10,000 times brighter than currently possible. This incredibly bright light will open new vistas of research in many fields of science and technology, including materials sciences, biology, medicine, biotechnology, chemistry, physics, and the geosciences. The APS will be available to researchers from the nation's academic, industrial, and government laboratories, who will gain access to the facility by submitting proposals or by joining consortia that own beam lines.

Light is one of the most important analytical tools in the research arsenal. The brighter the light, the faster data can be gathered, and the greater the detail revealed. The APS x-ray beams will permit studies of materials as complex as modern alloys, events as fast as chemical reactions, and biological systems as vital as the beating human heart.

The APS has received strong support from the scientific community. In recent years, national advisory panels set up by the Department of Energy and the National Academy of Sciences (Eisenberger-Knotek, 1984; Seitz-Eastman, 1984; Stehli, 1985; Brinkman, 1986; ERAB, 1987) have given the APS highest priority among new materials research facilities.

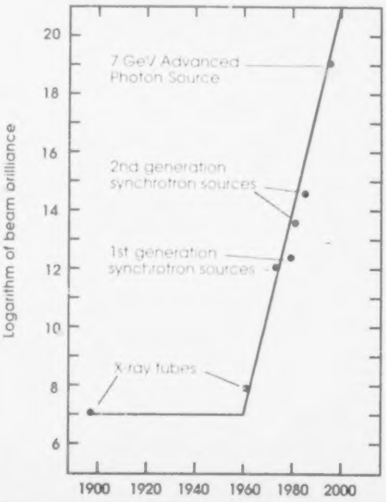
The APS will produce brilliant, narrow beams of x-rays by accelerating positrons (particles like electrons but positively charged) in a circular path at speeds near that of light. When the beam is bent by magnets, it emits energy in the form of x-rays. "Wigglers" and "undulators" — recently developed devices based on modern magnet technology — will vibrate the particle path over a short distance. The result will be the most brilliant beams of x-rays ever produced. As many as 100 beam lines will be available for research, approximately doubling the number of synchrotron x-ray beams available to the nation's researchers.

APS positrons will be accelerated to an energy of 7 billion electron-volts (7 GeV) and stored in a circulating ring. The greater this energy, the more focused and concentrated will be the x-ray beam.

The main APS building, where experiments will be performed, will be shaped like a doughnut with a circumference of about 3,500 feet. As many as 300 scientists and engineers will be able to perform experiments at the same time.

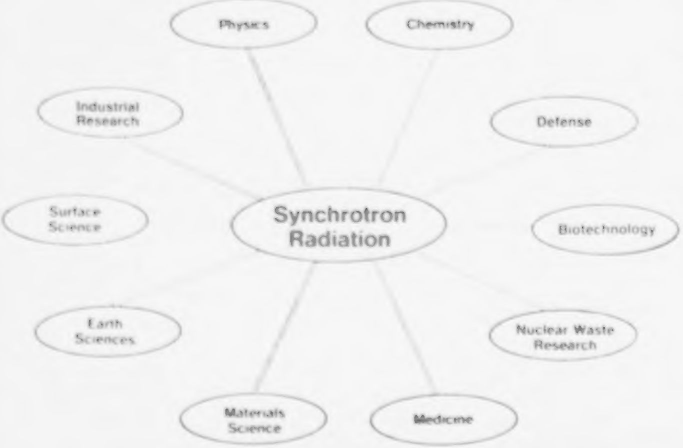
The APS project achieved an important milestone in 1987 when its conceptual design report, prepared by Argonne scientists and engineers, passed with flying colors an exhaustive preconstruction review by DOE's Office of Energy Research. Construction will begin in 1989 and be completed in 1994. The APS will significantly enhance the nation's prominence in both basic and applied sciences, and will contribute greatly to expanding America's high-technology capabilities. The long-term scientific and economic benefits of the APS have been recognized in Europe and Japan, where similar machines are being built.

History of x-ray sources



Almost 100 years ago, W. D. Coolidge discovered the first x-ray tube. X-rays have proven to be a powerful tool in research, industry, and medicine. Since the early 1960s, rapid advances have been made in the brilliance of x-ray beams for research. First generation synchrotron sources were electron accelerators from which materials scientists used "parasitic beams" of x-rays. Second generation synchrotron sources were built expressly to provide x-rays for materials research. The 7 GeV Advanced Photon Source, a third generation source, will provide beams 10,000 times more brilliant than those from previous machines.

The 7 GeV Advanced Photon Source at Argonne National Laboratory will open new realms of research in the structure of materials. Researchers will be able to perform more experiments in less time and gather better data than ever before. The resulting advances in materials and technologies will help the nation enhance its lead in technology and science and will stimulate the development of new high technology industries.


Physics
Chemistry
Industrial Research
Defense
Surface Science
Synchrotron Radiation
Biotechnology
Earth Sciences
Nuclear Waste Research
Materials Science
Medicine

The 7 GeV Advanced Photon Source will provide about 100 beams of x-rays for researchers. As many as 300 scientists and engineers at a time will be able to perform experiments in a variety of fields.

Revolution in materials science possible with APS

The 7 GeV Advanced Photon Source at Argonne will generate a materials science and engineering revolution that will help ensure the economic prosperity of U. S. industry through the next century. Crucial to technological progress is the invention of new materials with improved properties. Just as the Industrial Revolution was made possible by the invention of steel, future technological revolutions will be made possible by the invention of improved semiconductors, polymers, ceramics, superconductors, magnetic composites, metallic glasses, and artificially layered structures. These materials will find key applications in fields such as computing, microminiaturization, robotics, space exploration, communications, manufacturing, and many energy technologies.

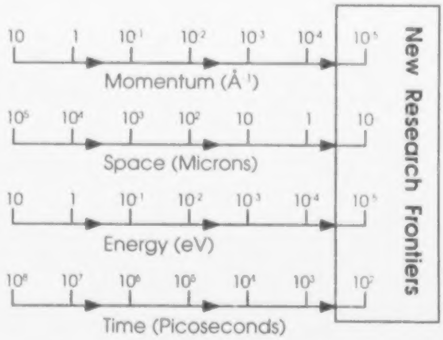
The brilliant beams of x-rays produced by the APS will provide the most sophisticated tools ever available for scientists to understand the behavior of new materials and the processes by which they are formed. The tremendous brilliance of APS x-rays can reveal the precise positions of atoms as new materials are formed, and the mechanism by which these positions give materials new and unusual properties. This knowledge will not only help form the basis for theoretical models of these materials, but also will help create other new materials with properties tailored to specific applications. In addition, research at the APS will provide a wealth of information about the magnetic and electronic structure of new materials, information that is essential to understanding their usefulness in advanced technologies.

Studies of metallic glasses provide an example of the kind of information the APS can provide. These materials, which are produced when molten metals solidify rapidly, are thousands of times stronger than materials used in present-day technologies. Their unusual strength is related to the "tangled" arrangement of their atoms. This arrangement follows patterns which are not yet fully understood. The APS will enable scientists to focus on this atomic detail and relate its tangled structure to its enhanced strength. Scientists will use this knowledge to predict structures of even stronger new materials.

A second example is provided by ceramics. Ceramic fibers are already being used for short-range information transmission, and ceramic mirrors have been designed for telescopes in future space shuttles. Recently, new ceramics have been discovered that lose all resistance to electricity at 90 degrees Kelvin. These superconductors promise exciting new technologies in such fields as electronics, power transmission, and transportation.

The promise of ceramics is great enough that future applications are expected to make them the "silicon chips" of the communications, space, and auto industries. But before this potential can be realized, scientists must achieve a fuller understanding of the behavior of these materials during their high-temperature formation. The ability to sharply focus the brilliant x-ray beam from the APS will permit researchers to examine the internal structures of ceramics under the most extreme conditions, such as ultra-high temperature and pressure.

7 GeV Advanced Photon Source

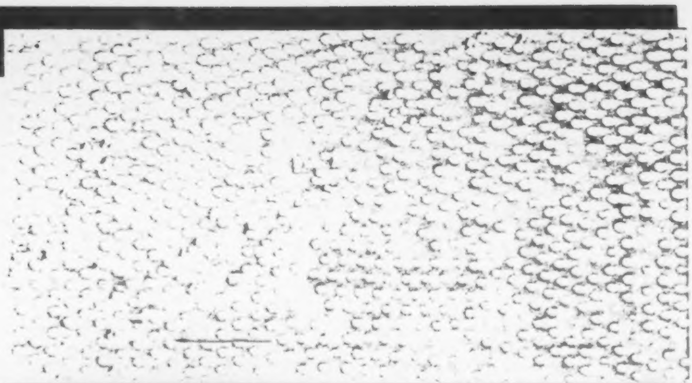


New frontiers to open in condensed matter research

Developments in condensed matter physics have been stimulated by the demand for new materials with improved properties. Condensed matter embodies in its conceptual framework four physical quantities — energy, momentum, time, and space.

Higher resolution in the measurement of these four fundamental parameters is expected from the ultra-high brilliance, collimation, time structure, and tunability of x-rays from Argonne's APS. Major advances in understanding condensed matter physics are expected to result.

Many areas of condensed-matter research will benefit from the APS. A few examples that have excited the imaginations of condensed matter physicists are dynamic excitations with thermal energies, nuclear-resonance Bragg scattering, magnetic scattering from monolayers, two-dimensional melting, wetting phenomena, and substrate and interface interactions.



Theoretical predictions for the atomic structure of a metallic glass suggest the tangled arrangement of atoms that produces the material's unusual strength. Research at Argonne's 7GeV Advanced Photon Source will test such imaginative theories.

Studies of material surfaces, such as an oxidized copper sphere, are crucial in determining the factors that control oxidation and corrosion. Research at the APS could lead to the creation of new materials that are more resistant to corrosion and failure.

U. S. industry will gain competitive advantages

As American industry moves into the 21st century, it faces formidable foreign challenges to its traditional supremacy in such high-technology fields as computers, electronics, aircraft, automobiles, and drugs. These challenges cannot be met by continuing to do business as usual. Instead, new products must be developed that give industrial and household customers superior performance, higher quality, and greater reliability, all at a lower cost. To help achieve these goals, advanced materials are needed.

Today, many advances in industrial technology are made possible by a historically unparalleled array of reliable, analytical techniques with high resolution. Leading the way are revolutionary advances in the use of photons for research — stimulated largely by work at synchrotron radiation sources throughout the world. The 7 GeV Advanced Photon Source at Argonne National Laboratory will provide photon beams 10,000 times more brilliant than any previously available, and will make available as many as 100 beams for experiments. Some beams will be dedicated as general user beams, available to researchers who submit short proposals. Other beams will be owned and operated by research groups. The APS will extend both the quantity and quality of materials research by American industry.

The extreme brilliance of APS x-rays will permit the study of strains and defects in semiconductors to a depth of several hundred micrometers. This nondestructive technique, known as topography, is needed to improve crystal growth processes and provide a deeper understanding of the structural changes that materials undergo during phase transformations from solid to liquid. Topographical research will also help develop improved methods to distribute dopants in semiconductors. Dopants are impurities intentionally introduced into semiconductors to alter their properties in desirable ways.

Industry's search for materials with higher strength and lower weight requires analytical probes that can reveal in a millionth of a second fine details at the atomic and molecular levels. The APS will have the brilliance and energy to provide key data on stresses, surface structures, two-dimensional phase transitions, phase equilibria and kinetics, size distribution of microscopic particles within structures, and detailed analyses of the elements within a material.

The APS will also accelerate studies of the structure of polymers, thereby aiding national efforts to develop light-weight polymers tailored to provide high-strength properties needed in advanced aerospace structures.

New superconducting ceramics that lose all resistance to electricity at 90 K could lead to faster and more powerful supercomputers, magnetic energy storage devices, and power lines that transmit electricity thousands of miles without loss. The APS will aid studies of the structure of these ceramics, and could help provide the detailed understanding needed to develop even higher-temperature superconductors.

New drugs and other biochemical products could result from APS studies in such fields as enzymes, photosynthesis, and chemical reactions.

Benefits to industry and society

The APS is expected to stimulate rapid advances in American industrial research. Here are some of the industries that could benefit:

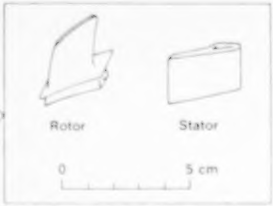
Aeronautics
Automobile
Biotechnology
Ceramics
Chemical
Communication
Computers
Defense
Energy storage
Environmental industry
Magnetics
Medical imaging
Nuclear energy
Oil products
Pharmaceuticals
Semiconductor
Space
Steel
Synthetic materials
Waste management

computers electronics aircraft automobiles pharmaceuticals

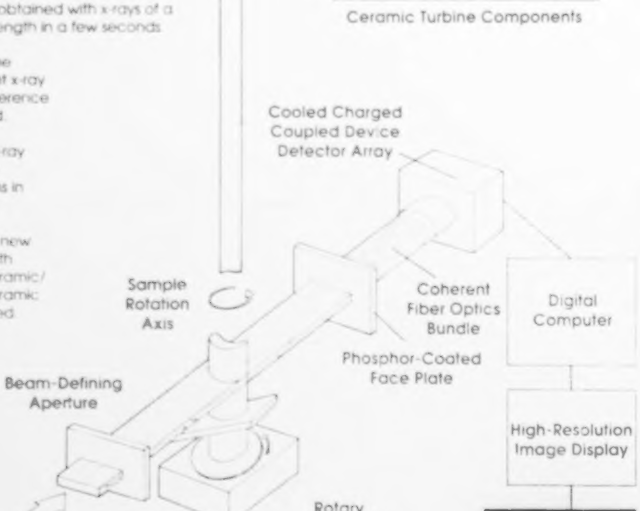
Industry

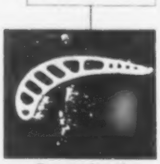
Industrial uses of x-ray tomography imaging

- X-ray computed tomography is a widely used method of obtaining three-dimensional views of dense objects ranging from advanced engine parts to oil source rocks.
- High-intensity x-ray beams from synchrotron light sources permit rapid acquisition of data needed to reconstruct images with resolutions down to one cubic micrometer.
- Rapid image-data acquisition allows potential failure-initiating defects in structural materials to be studied under dynamic loading conditions. This is not possible with conventional x-ray sources.
- The x-ray intensity from Argonne's Advanced Photon Source will be high enough that a tunable monochromator can be used, thus allowing images to be obtained with x-rays of a single energy or wavelength in a few seconds.
- Multiple x-ray images of the same object at different x-ray wavelengths allow "difference images" to be obtained. Properly processed by computer, difference x-ray images show chemical composition distributions in unprecedented detail.
- Uniformity of properties of new lightweight, high-strength composites, such as ceramic/ceramic or polymer/ceramic materials, can be studied.


Rotor
Stator
0
5 cm

Ceramic Turbine Components


Cooled Charged Coupled Device Detector Array
Coherent Fiber Optics Bundle
Digital Computer
Sample Rotation Axis
Phosphor-Coated Face Plate
Beam-Defining Aperture
High-Resolution Image Display
Rotary Stepper-Motor Stage
X-ray Beam from 7GeV Advanced Photon Source



Example of Computed Tomographic Image of Turbine Blade

Schematic layout of the computed tomographic imaging system

APS will reveal structure of key biological molecules

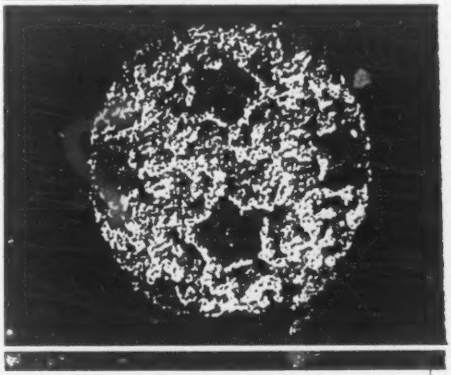
The 7 GeV Advanced Photon Source at Argonne will open new doors of biochemical inquiry. Because the APS will be so much more powerful than any x-ray source now in existence, many entirely new experimental methods will be developed with the APS. In addition, many current methods will work better and faster on the APS than anywhere else. While many dicoveries that will occur in biophysical chemistry and molecular biology have yet to be conceived, a few anticipated advances can be described.

For the first time, it will be possible to visualize the physical behavior of every atom in an enzyme while the enzyme catalyzes a chemical reaction. Three-dimensional "movies" of these complex biochemical machines can be made on the same time scale as their actual movements, and the function of every atom in an enzyme's structure can be determined. Such detailed knowledge will prove vital in the new, emerging field of "protein engineering." This field will create improved enzymes for industrial uses, and better drugs that modify the actions of specific enzymes.

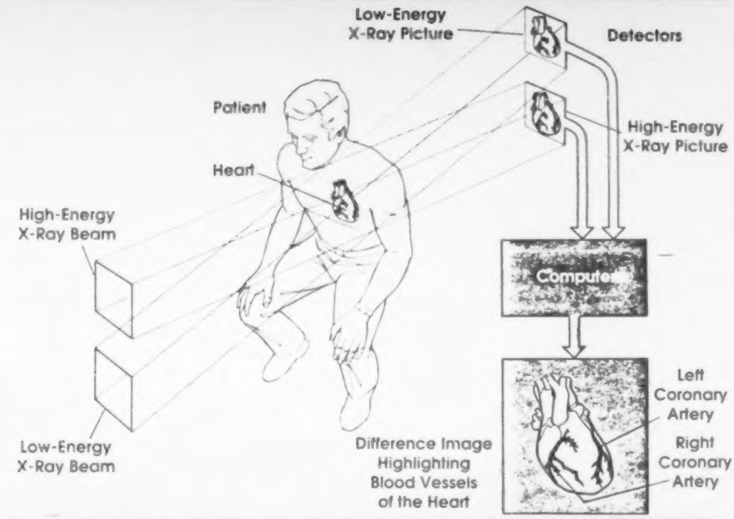
These practical achievements will be accompanied by a fundamental impact on the basic understanding of biochemical processes. No longer will scientists need to guess how enzymes work by studying rigid models, determined by measurements that take months or even years.

The APS will revolutionize the way structures of large biological molecules are determined, allowing study of the atomic architecture of molecules that currently elude understanding. The extreme brightness of the APS, combined with the ability to tune its beam energy, will create new ways to determine the precise positions of individual atoms in protein and nucleic-acid structures. Scientists will see how proteins bind to DNA, a process that regulates the expression of genes; they will see three-dimensional structures of viruses and study the way anti-viral drugs act against them; researchers will see how photosynthesis works, how biological luminescence occurs, how biochemical energy is converted into chemical reactions, and many other important phenomena in the world of molecular biology and biochemistry.

Some of these projects are now being carried out at existing synchrotron x-ray sources; for example, the entire structure of the virus that causes the "common" cold was recently determined using synchrotron radiation. But the APS source will be as much as 100 times more powerful than any existing facility. With the APS, data for studies of protein structures will be collected faster, more reliably, more accurately, and with greater detail than ever before.



The structure of the human cold virus is being used to probe the chemistry of anti-viral drugs at the atomic level. Scientists recently determined the structure of this simple human virus after months of data gathering at an existing synchrotron radiation source. With the brilliant beam from the 7 GeV Advanced Photon Source, the same data could be gathered in a single afternoon. By allowing the study of more complex viruses in less time, the APS will speed the rate of progress in such fields as molecular biology and protein crystallography.



APS promises improved tests for heart disease

Cardiovascular disease is the greatest health problem in the United States. The development of coronary-artery imaging at the APS will provide a powerful tool to study coronary-artery disease, heart attacks, and the response of coronary arteries to surgery. This work may lead to a method to screen large segments of the population for heart disease.

Each year, heart attacks kill as many as 600,000 people, half of whom never knew they had the disease. A safe test to screen for the disease might save them. Yet science knows little about the disease process, and methods for evaluating coronary arteries are risky and expensive.

Coronary angiography, or artery evaluation, is difficult because the heart and chest constantly move. Narrowing of these arteries, which are normally about 1 mm thick, leads to heart attacks. Heart arteries can be visualized by filling them with compounds containing x-ray-absorbing iodine and photographing the patient with x-rays. Normally this x-ray "dye" is injected directly into each coronary artery with a catheter passed through the patient's major arteries. Most risk from coronary angiography comes from catheterization and the large quantities of x-ray dye needed for the photographs.

Synchrotron radiation presents a safe way to perform angiography by avoiding catheterization and reducing the amount of dye. The method combines new computer techniques with the ability to precisely tune the energy of APS x-rays. The x-ray beam is tuned to the energy iodine absorbs most easily, and two images are taken simultaneously — one at that energy and one at a slightly lower energy. When a computer subtracts one image from the other, the image of the arteries is enhanced 150,000 times over that of bone or flesh. This extreme sensitivity allows use of much lower iodine-dye concentrations and lower x-ray doses, compared to conventional angiography. With such low iodine doses, the dye can be introduced through an arm vein.

Preliminary studies of these techniques are promising, and methods are being developed to exploit the high intensity of the APS storage ring to make the procedure even more effective. Experiments at other synchrotrons require a three-second scan of the patient's chest area. At the APS, an image can be formed in about three milliseconds, fast enough to make "snap shots" and "movies" of heart arteries. Such a possibility would make this technique clinically useful.

Chemistry:

Study of ultra-fast reactions, micron-sized crystals possible

Chemists using the Advanced Photon Source, will gain two important advantages: the ability to gather images that freeze chemical reactions in progress, and the ability to study crystals of micron size (one millionth of a meter) in finer detail than ever before. The APS will allow scientists to gather data thousands of times faster, or to gather thousands of times more data in the same time.

By gathering data faster, chemical reactions can be studied in as little as 40 billionths of a second. The fastest that data have been gathered using dedicated synchrotron light sources is about one thousandth of a second. The APS will let scientists gather data fast enough to effectively freeze an on-going chemical reaction in time. For the first time, it will be possible to determine the structures of intermediate compounds formed during fast chemical reactions. This capability could create a new field of chemical analysis, providing detailed insights into a variety of chemical and biochemical processes. Long-term results could be new drugs, more efficient industrial processes, and new chemical technologies.

By gathering more data in the same time, scientists can vastly improve the detail the data reveal. For chemists, this means the ability to determine detailed atomic structures of important chemical and biochemical substances, knowledge that is crucial to understanding complex materials. The APS will allow for the first time high-resolution structural determination of single crystals as small as a one-micron cube, about 200 times smaller than can be studied with existing synchrotron x-ray sources. For many materials important to modern technology only very small single crystals can be obtained. Among these materials are the zeolites and other important catalysts used in petroleum cracking and refining. Some 20 percent of America's gross national product comes from products that involve catalysis.

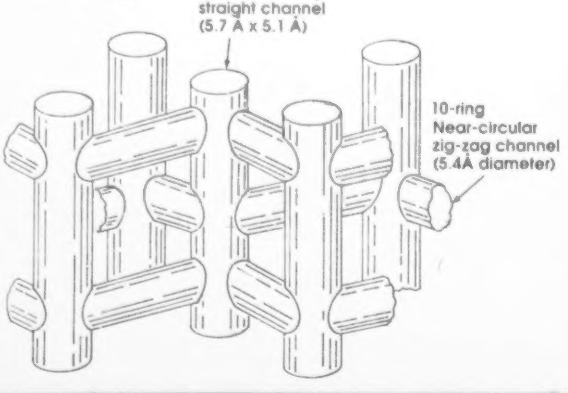
Improved ability to study catalysts could spur new industry, technology

Many important industrial and chemical processes are controlled by catalysts. Zeolites are an important class of catalysts widely used in the petroleum and petrochemical industries.

This network of tubes represents channels within the porous structure of the zeolite type ZSM-5. Their geometry makes zeolite-catalyzed processes highly selective, because only molecules of certain sizes and shapes can pass through the network. This selectivity is important in determining which chemicals participate in reactions and which products result.

The study of zeolite structures is vital to understanding their catalytic properties, but these studies are hindered because zeolites are difficult to grow in crystals large enough for conventional x-ray studies. The extreme brilliance of APS x-rays, however, will make it possible to study micron sized crystals — not only in zeolites, but in other materials as well. This research could lead to new chemical and industrial processes that are more efficient and productive than current processes.

Pore structure of ZSM-5 zeolite


Elliptical 10-ring straight channel (5.7 Å x 5.1 Å)
10-ring Near-circular zig-zag channel (5.4Å diameter)

Atomic processes:

APS photons will probe electron shells more deeply

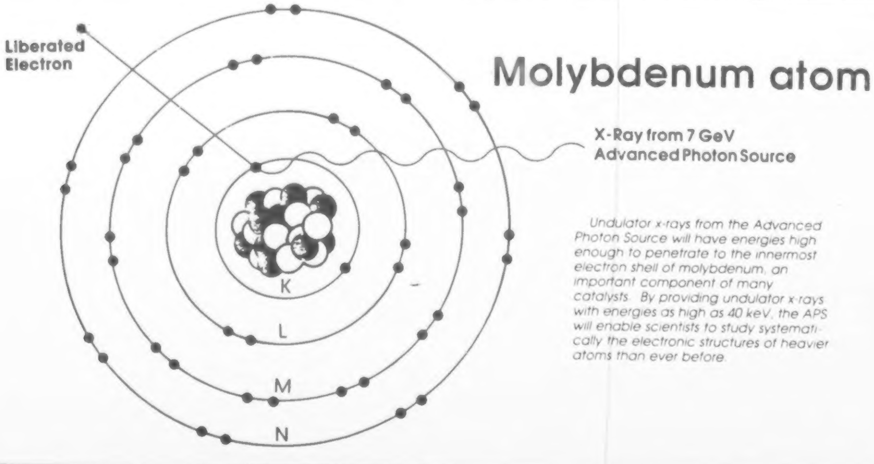
Argonne's 7 GeV Advanced Photon Source will provide x-rays with enough energy to excite electrons in virtually any atomic or molecular subshell, even those most tightly bound to the nucleus. It will be possible to probe the innermost shells of atoms in the lanthanide (often used in TV screens) and actinide (which includes uranium) regions of the periodic chart. High-quality experimental data are sparse for these elements. For the first time, it will become possible to test systematically theoretical methods for calculating atomic structure.

The unique properties of the APS photon beam will open other new avenues of atomic physics research. The APS will produce highly brilliant, pulsed beams in which virtually all x-rays have the same energy. Beams can be tuned to specific x-ray energies to match experimenters' needs. These key properties will make it possible to study atomic processes over the entire periodic table with minimal interference from background "noise."

Atoms on the surfaces of materials exhibit different electronic properties than free atoms. Surface properties are important in determining a material's ability to act as a catalyst, to resist corrosion or wear, to function in a microcircuit, and to contribute to other industrial applications. APS x-rays will give scientists the world's most sophisticated tool to understand surfaces of technologically important materials. The ability to probe the innermost electron shells of materials will advance many areas, such as catalysis.

APS x-rays can also be used to create ions (atoms with one or more electrons stripped away) that can be held essentially stationary in a trap. These stationary ions can be studied with great precision, or they can be extracted and used to study low-energy collisions between ions and atoms. This method of producing trapped ions promises dramatic improvements over current methods.

The trapping of ions, atoms, and molecules on the surface of materials is a complex phenomenon. When x-rays illuminate these surfaces, these trapped species are released. This process, called "photodesorption," has generated many unanswered questions in chemical physics. Future studies at the APS will address them in greater detail.



Undulator x-rays from the Advanced Photon Source will have energies high enough to penetrate to the innermost electron shell of molybdenum, an important component of many catalysts. By providing undulator x-rays with energies as high as 40 keV, the APS will enable scientists to study systematically the electronic structures of heavier atoms than ever before.

APS x-rays to advance studies of geological materials, forces

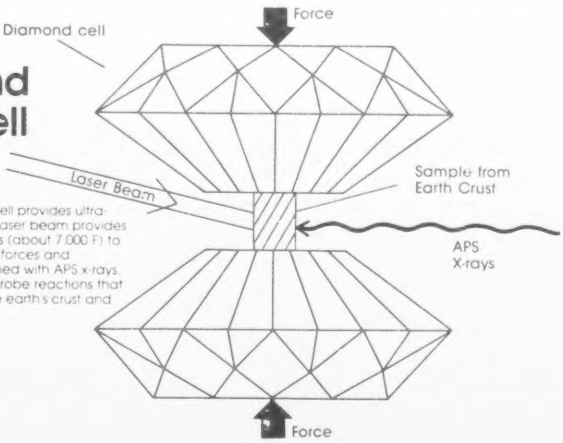
The quest to understand the structure of earth and its formation is as old as the human race. Even with modern scientific methods like computer modeling and simulation, geoscientists understand very little about the earth's origin, detailed structure, and age. Even simpler aspects, such as the increased earthquake and volcanic activity of recent years, demand closer study.

To understand the geochemical mechanisms of the earth's origin and the enormous forces involved in the formation of its crust, it is important to use modern techniques to simulate the high pressures and temperatures of geochemical activity. Synchrotron x-rays, such as those from the Advanced Photon Source, will provide unique opportunities to study the physical and chemical properties of geologic materials under such extreme conditions. The APS can be combined with a high-pressure diamond cell to provide geological-scale pressures and temperatures as high as 7,000 F. In such a laboratory, x-ray spectroscopy can reveal the structures of noncrystalline materials, and the locations and chemical states of trace elements in minerals.

The APS will also make it easier to study reactions between geological materials as they actually take place. It will be possible to study mechanisms of reactions and intermediate products that are created and consumed during the process. This new capability will permit scientists to simulate the formation of earth's crust.

Synchrotron x-rays also offer significant advances over conventional micro-analytical methods. Compared to currently used methods, synchrotron x-ray sources, like the APS, offer greater sensitivity and higher signal-to-background ratio. Compared to conventional x-ray diffraction studies, which rely on x-ray tubes, synchrotron x-rays offer improved resolution, higher data-collection rates, and smaller sample-size requirements. Compared to conventional x-ray topography methods, synchrotron light sources offer the ability to detect smaller structures and defects.

Diamond anvil cell



The diamond anvil cell provides ultra-high pressure and the laser beam provides ultra-high temperatures (about 7,000 F) to simulate geochemical forces and temperatures. Combined with APS x-rays, such instruments can probe reactions that could have formed the earth's crust and mantle.

geologicalmaterials noncrystallinematerials traceelementsinminerals

Education

Faculty, student opportunities for research, training will expand

By providing up to 100 beams, the 7 GeV Advanced Photon Source offers two major benefits to the nation's effort to educate future generations of scientists and leaders. It will greatly increase the opportunities for talented graduate students to work directly with scientists and professors on a world-class research facility, and it will directly address the current shortage of scientific instruments available to college and university scientists.

The APS is expected to double the number of synchrotron light experiments being performed in the United States. As many as 300 scientists will be able to perform research at a given time. In addition, by producing brighter beams than ever before, the APS will make it possible to gather more data in less time, thus making experiments faster and more productive.

This rise in research activity will greatly increase the number of graduate and undergraduate students who can gain hands-on experience. They will participate as members of research teams headed by the nation's leading scientists in such varied disciplines as materials science, biomedicine, chemistry, physics, and the geosciences. This kind of educational experience is crucial to developing future leaders for an era of increasing national and international sophistication in science and technology.

The APS will also directly address the national shortage of high-quality instruments at colleges and universities. The extent of the problem is partly reflected in the National Science Board's recent statement that the nation's undergraduate programs have declined in quality and scope to such a degree that they no longer meet national needs for students with hands-on experimental experience. The APS, with as many as 100 beam lines, will accumulate a steadily growing stock of innovative instruments to take advantage of the unique x-ray beams at this world-class research facility. It will provide a centralized national resource of state-of-the-art instruments available to visiting researchers, including faculty and students from across the country.

Student research participants at Argonne learn to use an x-ray diffractometer. More sophisticated x-ray instruments are being developed for research at the Advanced Photon Source.

User support

Broad technical support available to users of APS

The importance that the scientific community places on the 7 GeV Advanced Photon Source is reflected not only in the recommendations of national scientific panels, but also in the deep interest that future users have taken in contributing to its design. The APS Steering Committee, a body of users, has organized a series of workshops and meetings. These events have been well attended by representatives of machine physics and users groups, and various funding agencies that support research. Also attending were representatives of academic, industrial, and government laboratories who expect to sponsor large research projects at the facility.

Support at the state and local level is shown in the state of Illinois' commitment to support construction of housing for some 300 APS users.

Scientific staff

The Advanced Photon Source will be a center of interaction for hundreds of scientists from many disciplines and organizations. During experiments, APS users will have available the assistance of the facility's 300 full-time professional operating staff, and potential access to Argonne's approximately 1,250 scientists and engineers. In addition, some 300 fellow researchers will be performing research projects at the facility at any given time.

Computing services

APS users will have access to extensive, state-of-the-art computing facilities. Argonne's computing capabilities will soon be upgraded by a high-performance computer that will at least double the laboratory's on-site scientific computing power. APS users will also have access to new parallel-architecture computers at Argonne's Advanced Computing Research Facility.

Current facilities include two IBM 3033 computers and an IBM 3042 attached processor for batch and interactive general purpose computing, electronic mail to international networks, and access to major national networks, such as ARPANET, BITNET, DECNET, and MFENET. Access to MFENET provides the services of a Cray X-MP supercomputer. Argonne's computing services also include access to central output devices, such as high-speed laser printers, color film recorders, and various graphics plotters. In addition, the National Energy Software Center, located at Argonne, has a library of thousands of software packages developed by the Department of Energy.

Shop support

Argonne's machine and electronics shops provide support services needed to design, develop, and fabricate the special instrumentation needed by APS users. These shops specialize in fabrication skills needed to support cutting-edge research.

Library services

Eight on-site technical and scientific libraries at Argonne house more than 65,000 book titles, 950,000 technical reports, and 3,800 technical and scientific journals.

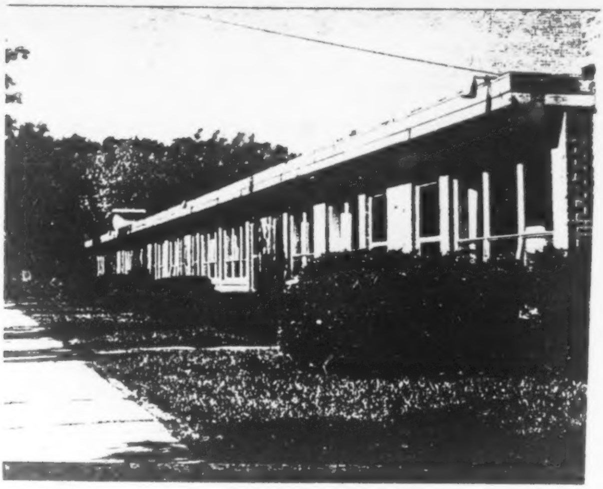
Through the libraries, scientists and users at Argonne can access all major computer data bases, including DIALOG, BRS, SDC, DOE/RECON, NASA/RECON, STN, and DOD/DROLS.

Interlibrary loan services include 24-hour retrieval from the University of Chicago's Regenstein/Crerar Library, and access to the holdings of the Center for Research Libraries.

Accessible location

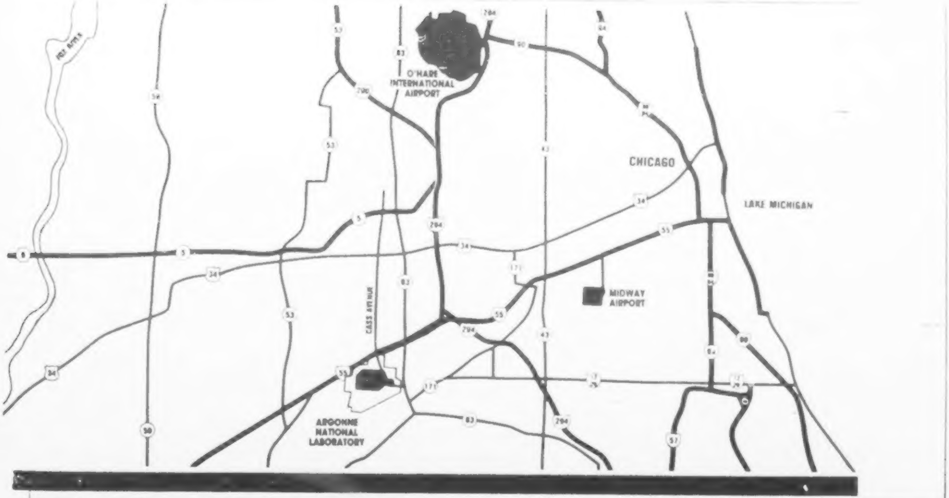
The APS will be easily accessible to scientists from all over the nation and the world. Argonne is about half an hour by car from O'Hare International Airport, the world's busiest airport, with connection to virtually all domestic and international airports. Several major universities and many industrial research laboratories are within a one-hour drive of Argonne.

User support



Lodging

The state of Illinois has promised to support construction of a new lodging facility for some 300 users when the APS is built. In the meantime, Argonne's existing lodging facilities provide required housing. In addition to users of the laboratory's many world-class research facilities, many visiting professors, students, research participants, post-doctoral appointees, and conference attendees use the lodging facility during their short visits to Argonne. Existing lodging facilities include 180 beds in 172 rooms, ranging from private apartments to student dormitories.


FOX RIVER
O'HARE INTERNATIONAL AIRPORT
CHICAGO
LAKE MICHIGAN
MIDWAY AIRPORT
CASS AVENUE
ARGONNE NATIONAL LABORATORY
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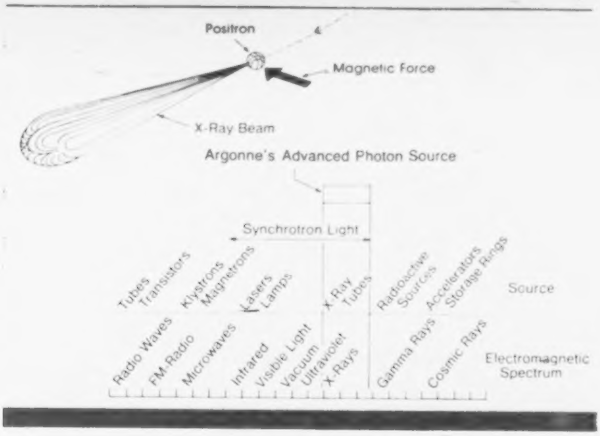
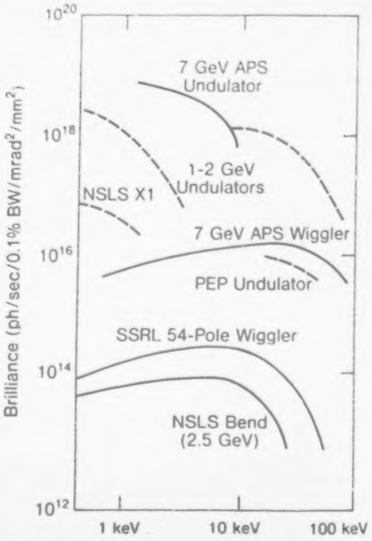
Synchrotron light properties


Positron
Magnetic Force
X-Ray Beam
Argonne's Advanced Photon Source
Synchrotron Light
Tubes
Transistors
Klystrons
Magnetrons
Lasers
Lamps
X-Ray
Tubes
Radioactive
Sources
Accelerators
Storage Rings
Source
Radio Waves
FM-Radio
Microwaves
Infrared
Visible Light
Vacuum
Ultraviolet
X-Rays
Gamma Rays
Cosmic Rays
Electromagnetic
Spectrum

Fast-moving, charged particles, such as electrons traveling very close to the speed of light, radiate energy when an electromagnetic force causes their direction or speed to change. This radiation is emitted in the forward direction in a very intense, narrow beam. In synchrotrons, magnetic fields bend the particles' path, and photons ranging in energy from the infrared to the x-ray region of the electromagnetic spectrum are emitted.



Through the use of wigglers and undulators, Argonne's Advanced Photon Source will produce x-ray beams in the energy range from 1 to 100 keV that are 10,000 times more brilliant than those available from bending magnets at Brookhaven National Laboratory's National Synchrotron Light Source (NSLS). Other synchrotron light sources depicted are proposed 1-2 GeV Undulators at Lawrence Berkeley Laboratory, NSLS X-1 at Brookhaven, proposed 7 GeV Wiggler at Argonne's APS, PEP Undulator at Stanford University, and the SPEAR 54-Pole Wiggler at Stanford.

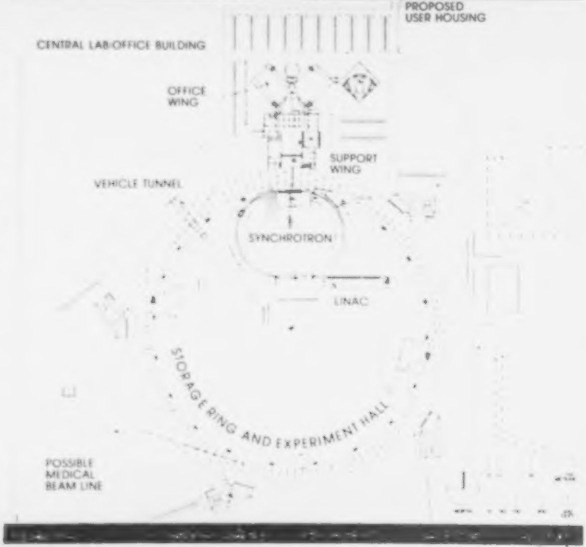
Devices made up of arrays of magnets wiggle or undulate the path of the charged particle as it passes through them. The light emitted from each wiggle adds up and is concentrated in a laser-like spot. In many cases, the power in the spot is more intense than the power at the sun's surface. The spot contains specific colors because only certain frequencies of the electromagnetic spectrum are generated. Devices that produce specific frequencies are called undulators.

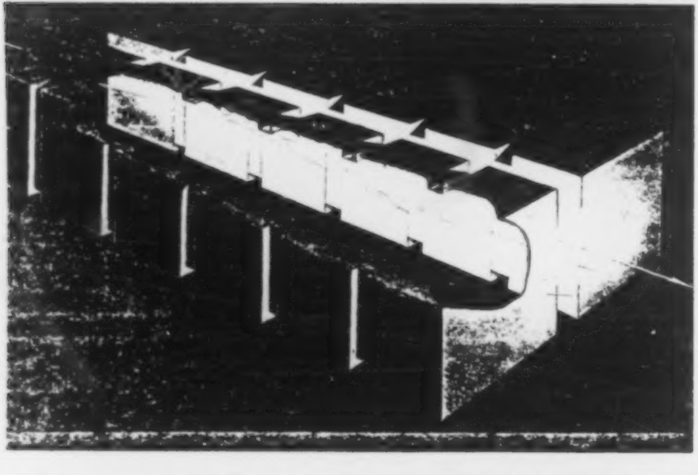
T6 [illegible] – wigglers, undulators, highest brilliance at high energy, laser-like spot

Evolution of the APS

In October 1984, after DOE's Eisenberger-Knotek Report and the National Academy of Sciences Seitz-Eastman Report, DOE organized a program review meeting at Ames, Iowa. At the meeting, scientists from the synchrotron-radiation users community and accelerator experts from many laboratories formed the APS Steering Committee to coordinate APS activities. They agreed on a design approach and model parameters for a storage ring with insertion devices. No fundamental technical obstacles to building the facility and achieving the design parameters were found. Since that meeting, the committee has organized several workshops to ensure that the facility's design incorporates the latest in scientific thinking.

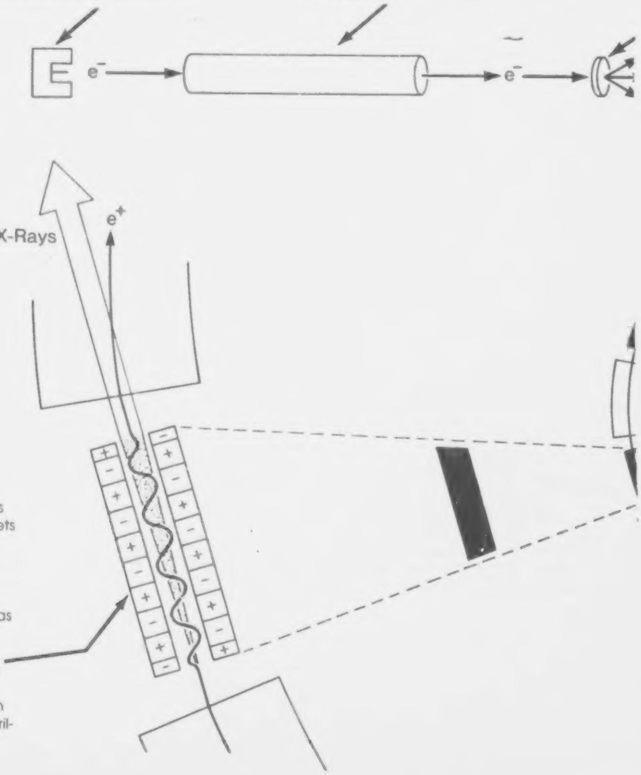
The conceptual design for APS construction was completed by Argonne scientists and engineers and approved by DOE in early 1987. DOE has granted funding for preconstruction research and development. Besides Argonne, many universities and national laboratories will contribute to this effort.


PROPOSED USER HOUSING
CENTRAL LAB/OFFICE BUILDING
OFFICE WING
SUPPORT WING
VEHICLE TUNNEL
SYNCHROTRON
LINAC
STORAGE RING AND EXPERIMENT HALL
POSSIBLE MEDICAL BEAM LINE



Anatomy of the APS

In the Advanced Photon Source, 7 GeV positrons (positively charged electrons) moving at nearly the speed of light will be forced to change direction by bending their paths with magnetic fields. Under these conditions, positrons radiate x-rays. To accelerate positrons and produce x-rays, a number of steps are required. The process begins in the ...



A. Electron Gun
Electrons are produced in the electron gun in the same way as in the picture tube of a television set. The electrons are injected into the ...

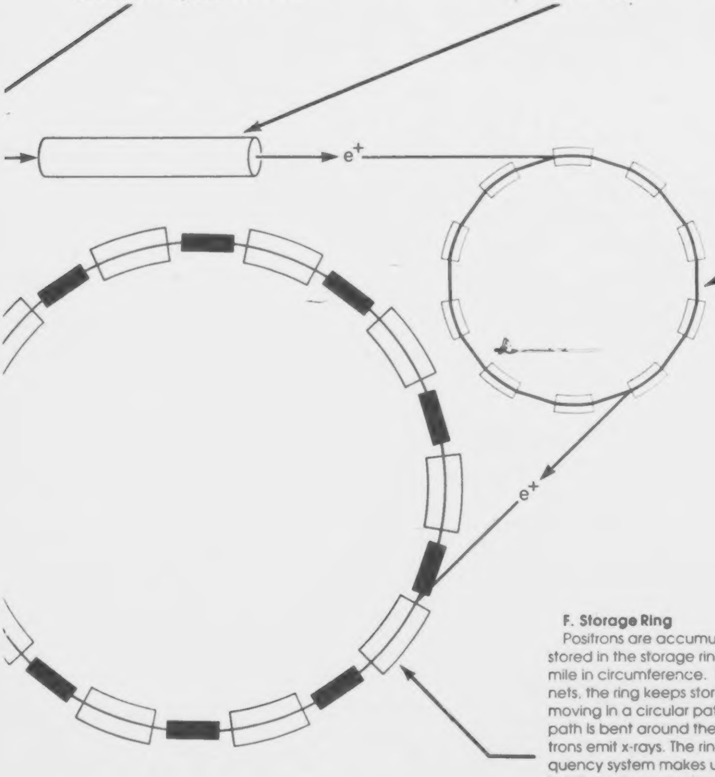
B. Electron Linear Accelerator
This accelerator boosts electrons to 200 million electron-volts and speeds near that of light. The electrons are aimed at the ...

G. Insertion Devices
An insertion device is a series of short magnets with alternating magnetic fields. This alternating field causes positron paths to "wiggle" or "undulate" as the particles pass through the device. Since the positrons are forced to change direction many times in a short distance, the brilliance of the x-rays is greatly increased.

Anatomy of the APS

C. Positron Target
This thin tungsten sheet interacts with high-energy electrons to produce electron-positron pairs. Positrons of appropriate energy are selected and injected into the ...

D. Positron Linear Accelerator
The positron linear accelerator raises positron energies from 10 million electron-volts to 450 million electrons-volts. The positrons are then injected into the ...

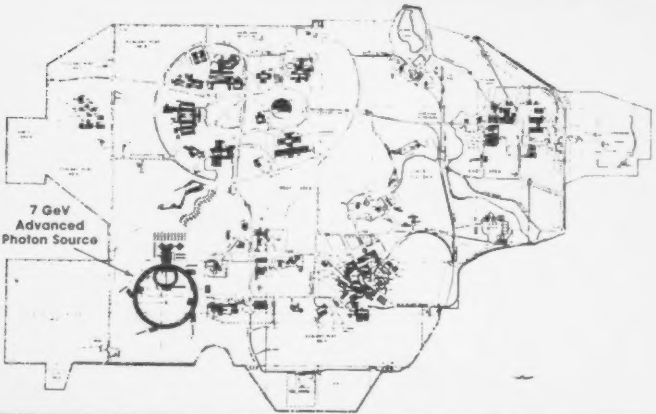


E. Booster Synchrotron
In this circular accelerator, positrons are accelerated to an energy of 7 billion electron-volts in 1/3 of a second and are then injected into the ...

F. Storage Ring
Positrons are accumulated and stored in the storage ring about 2/3 mile in circumference. Using magnets, the ring keeps stored positrons moving in a circular path. As their path is bent around the ring, the positrons emit x-rays. The ring's radio-frequency system makes up the energy lost through synchrotron radiation. This ring also provides straight sections into which can be inserted as many as 35 devices called ...

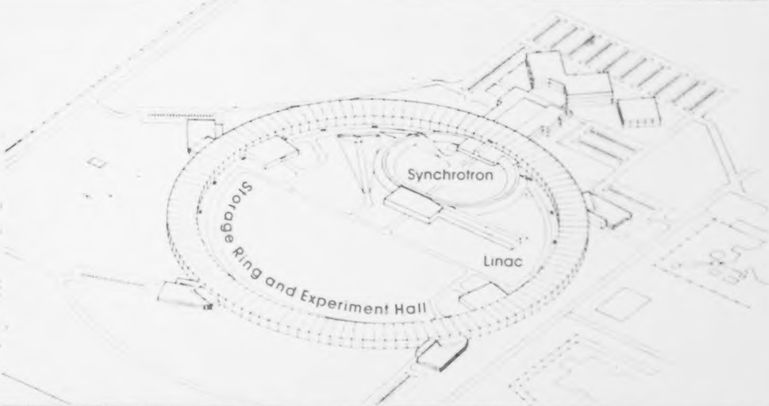
Architectural design

Argonne National Laboratory


7 GeV
Advanced
Photon Source

Site plan

The Advanced Photon Source will be located in the southwest corner of Argonne National Laboratory. Other sites were considered; this one was chosen because of its favorable terrain and its isolation from traffic and other sources of vibration that could interfere with sensitive experiments.


Synchrotron
Storage Ring and Experiment Hall
Linac

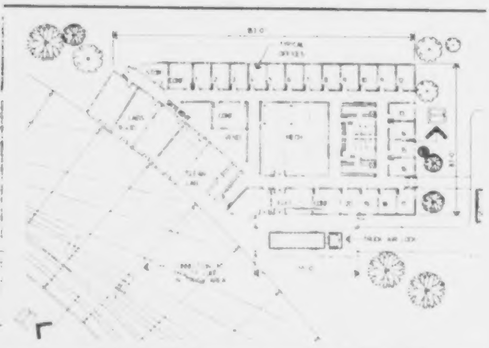
Isometric view of facility

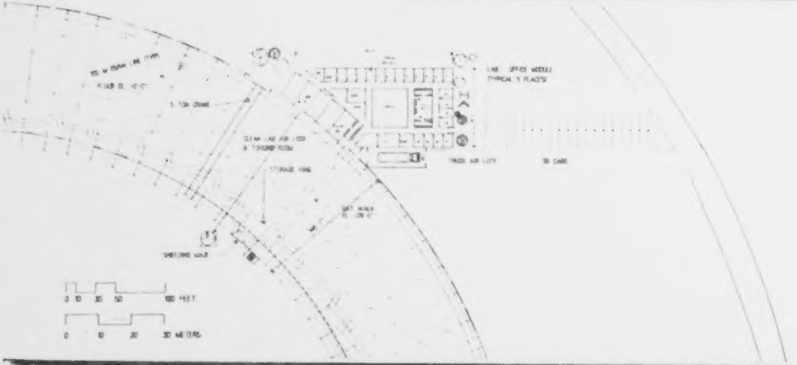
The doughnut-shaped building houses the 7 GeV storage ring and experimental hall. External buildings are the project center and laboratory-office buildings for visiting experimenters. The linear accelerators and synchrotron are in the infield.

Architectural design

Laboratory/office space

Offices and laboratories for visiting experimenters will be located around the outside of the experimental hall, which is about two-thirds of a mile in circumference. This arrangement will permit scientists to be close to their experiments. Laboratory/offices will be oriented to minimize interference with tangential beam lines.


TYPICAL OFFICES
MECH
TRUCK AIR LOCK


5 TON CRANE
LAB / OFFICE MODULE
TYPICAL 5 PLACES
STORAGE RING
TRUCK AIR LOCK
50 CARS
SHIELDING WALL
0 10 30 50 100 FEET
0 10 20 30 METERS

Funding for this publication was provided by the University of Chicago. Argonne National Laboratory is operated by the university for the U.S. Department of Energy.

Mr. **Bruce**. Thank you, Dr. Schriesheim. Dr. Wiley, from the Pacific Northwest Laboratory, the Director there. Dr. Wiley, we will hear from you now.

STATEMENT OF DR. WILLIAM R. WILEY, DIRECTOR, PACIFIC NORTHWEST LABORATORY, RICHLAND, WA

Dr. **Wiley**. Thank you, Mr. Chairman. It is worthwhile being third on the listing here sometimes, because I could just—are there any questions.

Mr. **Bruce**. Only in the hanging.

Dr. **Wiley**. Seriously though, many of the statements that have been made about technology transfer, about university programs, I will spare you and just enter that as a part of my written statement just refer to some key items that I have identified out of that document, if that's okay with you.

Mr. **Bruce**. Without objection, all of the full statements will be entered into the record.

Dr. **Wiley**. Mr. Chairman and Members of the Committee, I am awfully pleased to be here today, to represent the Pacific Northwest Laboratory. Approximately one year ago, during my first appearance before this Subcommittee, I discussed the research and development programs and unique features of PNL, as one of the Department of Energy's multi-program National Laboratories.

This year I would like to discuss the critical importance of DOE's Supporting Research and Technical Analysis budget, not only to these Laboratories but to the U.S. scientific community as a whole. Also, you requested in your letter of invitation that I discuss a major new scientific initiative at the Pacific Northwest Laboratory, which is to establish a Molecular Science Research Center.

Before I get into a discussion of the Molecular Sciences Research Center, I would like to talk about the importance of basic research to the needs and problems of the country. Over the past few years, several reports have identified the important role that basic research plays in the technology development as well as the relationship between technological advancements and the economic development of our country, and indeed, some of the regions within our country.

Both the Administration and the Congress have accordingly placed strong emphasis on enhancing support for basic research across scientific and engineering disciplines. Some of the most significant technical challenges facing the United States relate to energy development and stemming the degradation of our environment as a result of energy uses, and industrial competitiveness of course. All of these missions are, of course, part of the Department of Energy mission.

The complexity of some of these challenges exceed the knowledge base, the basic fundamental knowledge base of the scientific community. We are unable to solve these problems because of the lack of knowledge coming from basic sciences. Current methodologies and equipment cannot be expected to meet tomorrow's challenges, nor can they be expected to produce tomorrow's technologically-based business and economy.

Basic research has always been the principal source of new knowledge, leading to the understanding of complex problems. The pace of science has progressed to the point where molecular-level research, that very fundamental basic research, the interaction of molecules with each other, has clearly emerged as an area that promises to provide scientific breakthroughs.

The experience at PNL has shown that the key to making progress in several scientific programs lies in understanding the processes and the mechanisms at the molecular level. Whether the challenge is developing advanced materials, converting coal to clean fuels, or treating hazardous waste, the key to all of the understanding of this is at the molecular level, a very fundamental basic research effort.

The Supporting Research and Technical Analysis budget of DOE is a principal source for basic research support at DOE's multi-program laboratories, as well as the source of the majority of the research grants made by DOE to the universities. Likewise, the supporting research budget is the budget category in which the new state-of-the-art scientific facilities at DOE's multi-program laboratories are being funded.

Simply stated, the Supporting Research and Technical Analysis budget is one of the most important components of the Federal budget for maintaining the basic research capabilities of the U.S. and especially the scientific community. I urge this Committee to continue its traditional and strong support for this budget.

I want to turn now to a discussion of the Molecular Science Research Center, which we refer to as a basic resource for small science in the country. During my appearance before this Subcommittee last year, I briefly mentioned Pacific Northwest Laboratory's plans relating to a new scientific initiative called the Molecular Science Research Center.

The primary purpose of the MSRC, which I will refer to it here, will be to revitalize the Laboratory's basic research capabilities, while at the same time creating a national user facility which will be made available to the research teams from academia, industry and the Government laboratories.

The MSRC is intended to be a laboratory with state-of-the-art equipment, such as tunneling electron microscopes, NMR, nuclear magnetic resonance, and computer capabilities far beyond what we have today. All of this will bring together in one location, theorists and experimentalists in an interdisciplinary environment. The overall goal is to accelerate the process by which knowledge derived from basic research can be extrapolated with the assistance of computers, to new applications, thereby expediting the transfer of technology to the marketplace.

I want to briefly give you some idea of where we are in the development of this unique basic fundamental science facility. In 1986, PNL established an advisory committee comprised of representatives from industry, universities, DOE Laboratories, and other institutions throughout the country. The purpose of this was to get this community to help us identify the research themes that would be the focus of the Laboratory's new thrust in molecular sciences.

In 1987, October of 1987, PNL hosted a workshop of more than 200 people to hear the wider scientific community discuss what the research needs were of the molecular sciences center. The report of the workshop proceedings, entitled: "Chemistry at Interfaces" was published in January of 1988.

I might just point out, Mr. Chairman, that in this week's editorial of *Science* magazine, there's a kind of reaffirmation of the fact that the molecular interfaces is a key component to solving many of the chemical, biological and physical problems that we will face in the future.

We have met with several representatives of the university research community in the Pacific Northwest and elsewhere in the U.S., to brief them on the concept of the MSRC and to explore ways of joint collaboration in conducting research at these facilities. The concept is to be able to do research in the manner that one does research in the basic small sciences while at the same time, providing a larger sector of the scientific community with frontier level equipment and instrumentation.

We have also met with representatives from industries in the Northwest and throughout the United States, to solicit their input and their participation in this user facility. PNL has committed funds from its exploratory research budget to develop research proposals to date. This has permitted us to purchase equipment and to recruit staff for a small sector of what the center will be in the future.

The formal research proposal, as was indicated by Dr. Decker today, was submitted to the Department of Energy on March 1. I am confident that the peer review which the proposal is going through at the moment will suffice and we will be able to get on with this important facility, which will be the first of such a facility in the United States. There is one other facility located in Okasaki, Japan.

The MSRC is intended to focus on fundamental interactions of molecules in the complex heterogeneous environment. The MSRC will be a user facility,-as I have often repeated, available to visiting scientists from the industrial and academic communities. It will be an opportunity for those scientists who, for reasons of not having sufficient instrumentation and equipment, to proceed at frontier levels of science. The MSRC will be an educational training resource for undergraduate students and graduate students in science throughout the country.

I want to turn now to why the MSRC at PNL. Very simply, a laboratory, whether a part of the Federal laboratory system, the university system, or a component of the industrial company, must have leading edge equipment and instrumentation or it cannot perform excellent research. Moreover, it cannot attract first-rate scientists or faculty, and it is not the first choice of the best and the brightest graduate students in the country.

A laboratory must keep pace with scientific advances in equipment and instrumentation, especially if it is to have technology development as its major mission. To solve the applied problems given to us by DOE, we need this facility.

Let me summarize then. A stable research and development policy and a continuing commitment to basic science are keys to the economic strength of this country. While the U.S. still spends more than any other country on research and development, the percentage of civilian research has remained constant over several years. Meanwhile, our competitors have increased their expenditures for civilian research programs and are beginning to challenge our pre-eminences in our technology based market areas.

For the first time in 1986, the U.S. trade balance in high-technology goods was negative. Basic research is the important investment in our country's future. Just as we learned in 1970 that oil was an important ingredient to economic strength, we should be just as mindful that a strong commitment to basic research is equally important to our economic strength.

The supporting Research budget of DOE is a vital component of this commitment. Again, I would like to thank you for your continuing and strong support for this budget. I hope that we can expect that in the next couple of years.

Thank you very much, Mr. Chairman and Members of the Subcommittee.

[The prepared statement of Dr. Wiley follows:]

Statement of

DR. WILLIAM R. WILEY

Director

Pacific Northwest Laboratory

Before the

Committee on Science, Space, and Technology

Energy Research and Development Subcommittee

United States House of Representatives

Washington, D.C.

March 23, 1988

Introduction

Madam Chairman and Members of the Subcommittee, I am pleased to be here today on behalf of the Pacific Northwest Laboratory (PNL). Approximately one year ago, during my first appearance before this Subcommittee, I discussed the research and development programs and unique features of PNL as one of the Department of Energy's multiprogram national laboratories. This year I would like to discuss the critical importance of DOE's Supporting Research and Technical Analysis budget not only to these laboratories but to the U.S. scientific community as a whole. Also, as you requested in your letter of invitation, I will discuss a major new scientific initiative at PNL to establish the Molecular Science Research Center.

The Importance of Basic Research

Over the past few years, several reports have identified the important role that basic research plays in technology development, as well as the relationship between technological advancements and the economic development of a country or region. Both the Administration and Congress have accordingly placed strong emphasis on enhancing support for basic research across all scientific and engineering disciplines.

Some of the most significant technological challenges facing the United States relate to energy development, environmental degradation, and industrial competitiveness--all missions of the Department of Energy. The complexity of some of these challenges, however, already exceeds the sophistication of the equipment needed to solve specific problems. Current technology and equipment cannot be expected to meet tomorrow's challenges, nor can they be expected to produce tomorrow's technologies.

Basic research has always been the principal source of new knowledge leading to the understanding of complex problems. The pace of science has progressed to the point where molecular level research has clearly emerged as an area that promises to provide scientific breakthroughs. Experience at PNL has shown that the key to making progress in several scientific programs lies in understanding the processes and mechanisms at the molecular level. Whether the challenge is developing advanced materials, converting coal to clean fuels, or treating hazardous wastes--the key is in understanding processes at the molecular level, i.e., basic research.

The Supporting Research and Technical Analysis budget of DOE is the principal source for basic research at DOE's multiprogram laboratories, as well as the source of a majority of the research grants made by DOE to universities. Likewise, the Supporting Research budget is the budget category in which new state-of-the-art scientific facilities at DOE's multiprogram laboratories are being funded. Simply stated, the Supporting Research and Technical Analysis budget is one of the most important components of the federal budget for maintaining the basic research capabilities of the U.S. scientific community. I urge this Committee to continue its traditional strong support for this budget.

The Molecular Science Research Center--A Basic Research Resource for "Small" Science

During my appearance before this Subcommittee last year I briefly mentioned PNL's plans relating to a new scientific initiative called the Molecular Science Research Center (MSRC). The primary purpose of MSRC will be to replenish the laboratory's basic research capabilities while at the same time creating a national user facility which will be available to research teams from academia, industry, and other government laboratories. MSRC is intended to be a laboratoy with state-of-the-art equipment (tunneling electron microscopes, large molecule mass spectrometers, two dimensional NMR's, advanced laser measuring devices, a large photolysis chamber, computers, etc.) that will bring together in one location theorists and experimentalists in an interdisciplinary environment. The overall goal is to accelerate the process by which new knowledge derived from basic research can be extrapolated with the assistance of computers to new applications and thereby expedite the transfer of technology to the marketplace.

Background

In 1985, after having been designated an Energy Research multiprogram laboratory by the Secretary of Energy, PNL began the process of developing a new scientific initiative that would fulfill three criteria:

1. Provide a new capability with leading edge equipment for conducting DOE-sponsored research programs at PNL.

2. Provide interested scientists from the universities and industrial research community a "user" facility with a collection of equipment that would not otherwise be available in one location to address today's complex problems.

3. Provide a new resource for undergraduate and graduate students to participate in laboratory research as part of their degree process.

At approximately the same time that PNL was beginning its planning process, the National Research Council issued its report entitled "Opportunities in Chemistry." The so-called Pimentel Report identified several scientific challenges relating to energy and the environment that were dependent upon fundamental chemistry research. The Report also recommended that DOE establish a major initiative in those areas of chemistry relevant to the energy technologies of the future, and that new mechanisms be developed for strengthening the links between industrial and academic research. The Energy Research Advisory Board (ERAB) subsequently reviewed the Pimentel Report and recommended that DOE implement the recommendations, including the recommendation that appropriate multiprogram national laboratories increase their emphasis on basic research in one or more of the chemistry areas central to energy technologies. In effect, the NRC and ERAB reports provided the holistic background to PNL's scientific initiative.

In 1986, PNL established an Advisory Committee comprised of representatives from industry, universities, and the DOE laboratory community to help us identify the research themes that would be the focus of the laboratory's new thrust. A listing of the MSRC Advisory Committee is attached to my testimony.

In October 1987, PNL hosted a workshop to hear from the wider scientific community about what the research needs were in the molecular sciences. A report of the workshop proceedings entitled "Chemistry at the Interfaces" was published in January of 1988. A copy of the workshop summary is attached.

We have met with several representatives of the university research community in the Pacific Northwest to brief them on the MSRC concept and to explore ways of joint collaboration in conducting research. Meetings have already been held with high level officials from the Universities of Washington, Oregon, and Idaho, as well as Washington State, Oregon State, the Oregon Graduate Center, and the Oregon Health Sciences Center. In fact, we already have collaborative projects with research teams from the University of Washington, Washington State University, Washington University in St. Louis, and Rutgers University.

We have also met with representatives from industries located in the Pacific Northwest to solicit their input on specific research needs. Discussions have already been conducted with Boeing, Weyerhauser, Immunex, John Fluke Company, and Tektronix.

PNL has committed funds from its Exploratory Research budget to develop research proposals, to purchase equipment, and to recruit staff that will form a small nucleus of the Center. In fact, we have dedicated a portion of one of our laboratories at Battelle to establish a molecular modelling laboratory where the evolving research group and equipment are located.

The formal research proposal for MSRC was submitted to DOE on March 1. The total estimated cost for the laboratory and equipment is $125 million. If all goes well, we hope to be able to have the MSRC functional in five years. In the meantime, because this Center is so important to PNL's long-range future and our basic research capabilities, we have initiated conceptual design of the laboratory. It is expected that this design will be completed by mid-summer of 1988.

The Role of "Small" Science

Over the past few years we have heard much about "big" science or "mega projects", e.g., supercollider, superconductivity, supercomputers, the national aerospace program, the space station, etc. All of these projects represesnt scientific challenges that are very important to science and international competiveness. Research at the MSRC will, however, focus on "small" science. I believe very strongly that "small" science will continue to have a very important role to play in our scientific endeavors; in fact, with limited resources available for each university and small entrepreneur, the collection of equipment at MSRC will ensure that "small" science can continue with the same success rate as in the past.

MSRC is intended to focus on fundamental interactions of molecules in complex heterogeneous structures. The study of chemistry in these systems is defined as molecular science. Molecular science is a critical component of many research programs at PNL and a critical component of many of America's scientific challenges--design of advanced materials, e.g., superconductors; atmospheric pollution, e.g., acid rain and CFC's; hazardous and nuclear waste treatment and disposal; alternative fuels development, e.g., clean coal technology; and health research, e.g., AIDS, low level radiation, etc.

MSRC will be a user facility available to visiting scientists from the industrial and academic communities. In addition to a dedicated core of PNL scientists associated with MSRC, we hope to have an equal number of visitors doing research at any given time. These visitors would include post-doctoral assignments and faculty appointments.

The MSRC will be an educational training resource for undergraduate students, graduate students, and faculty-student teams. The national laboratories are unique resources that should be more fully utilized to enhance the educational training experience of undergraduate and graduate students. The MSRC will be a new opportunity on a scale not now available for training the next generation of scientists and engineers.

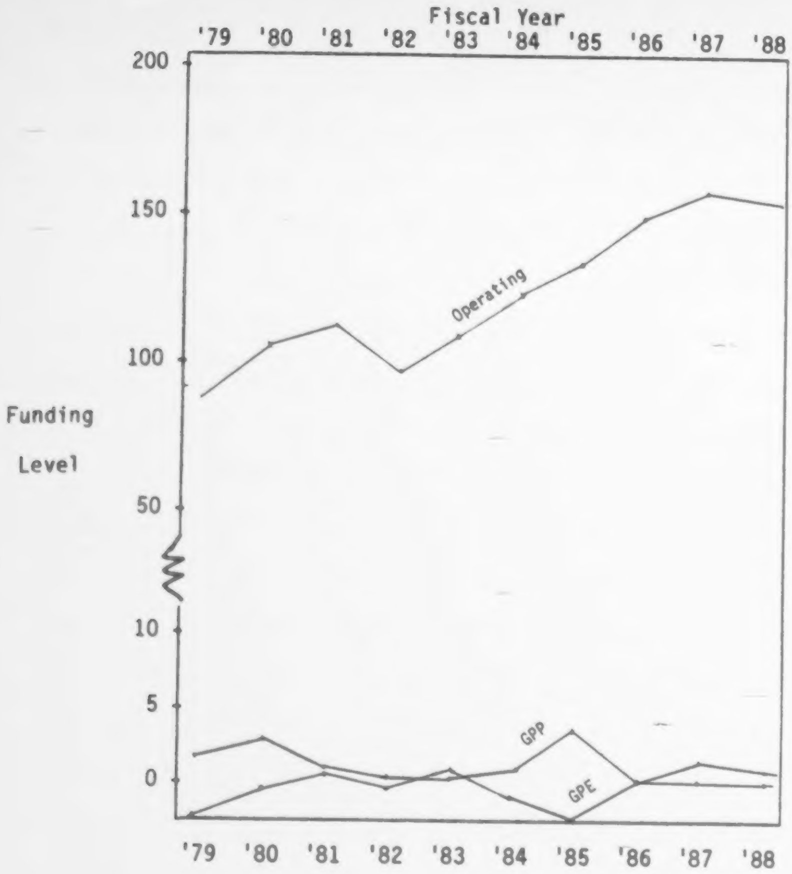
Why MSRC at PNL?

Why is MSRC so important to PNL and its ability to conduct first-rate research for the Department of Energy and other research sponsors? Simply stated, a laboratory--whether a part of the federal laboratory system, the university system, or a component of an industrial company--must have leading edge equipment or it cannot perform excellent research. Moreover, it cannot attract first-rate scientists or faculty, and it is not the first choice of the best and brightest graduate students. A laboratory must keep pace with scientific advances in equipment and instrumentation, especially if one's primary mission is technology development.

PNL was established as an entity in 1965 when the federal government separated out the "laboratory" portion of the Hanford operations and made operation of the Pacific Northwest Laboratory a separate contract. Over the ensuing twenty-three years, the mission of PNL has expanded and diversified. Today, PNL is a DOE multiprogram laboratory comprised of approximately 3,500 scientists, engineers, and support staff conducting research across a broad spectrum of issues and disciplines.

While PNL's staff and research volume has grown over this period of time, the technical capabilities needed for a laboratory of this size have not kept pace. The following chart illustrates this point; this situation is one of the most critical challenges facing me as the Laboratory Director:

PACIFIC NORTHWEST LABORATORY FUNDING SUMMARY
($ in Millions)



The message is self-evident--over the past ten years the laboratory has grown by 50 percent, but our facilities and equipment budget has remained basically "flat." What is worse is the fact that the last scientific laboratory resource funded by the federal government at PNL was authorized by Congress in 1968 and became functional in 1971.

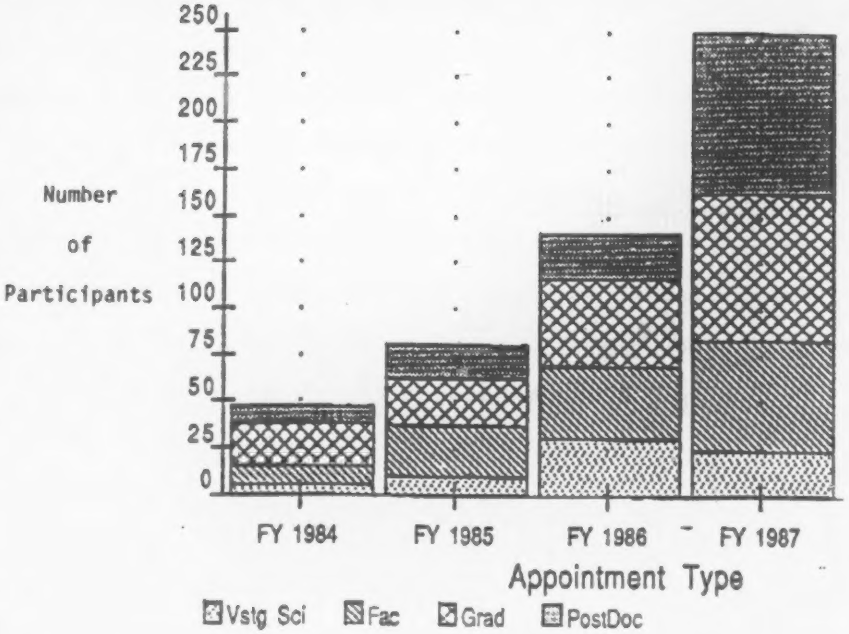
Thus, a span of twenty years has passed since our principal sponsor has provided new state-of-the-art laboratories for conducting basic research. I do not believe it requires further elaboration to state that the MSRC is an absolute necessity if PNL is going to continue to be a multiprogram national laboratory with an expectation and commitment to do first-rate scientific research in support of several programs of national and regional importance, e.g., acid rain, mapping the human genome, radon, research, environmental monitoring at Hanford, hazardous waste management, development of new high-strength materials, and alternative fuels development.

University Research Support

One of the other components of the Supporting Research Budget I would like to discuss today is University Research Support. Several recent reports have challenged the national laboratories to work more closely with universities in developing collaborative research proposals, to make equipment in the national laboratories available to university researchers, and to create more opportunities for students (undergraduate and graduate) to participate in laboratory research experiments. Since being designated an Energy Research laboratory in 1985, PNL has been aggressively responding to these new challenges, as evidenced by the following chart:

PACIFIC NORTHWEST LABORATORIES

UNIVERSITY RESEARCH PARTICIPATION



Much of this is accomplished at PNL through the Laboratory-Cooperative program that is administered through the Northwest Colleges and Universities in Science (NORCUS). The Laboratory Cooperative program is vitally important in creating opportunities for faculty and students to participate in laboratory research, and needs the continuing strong support of Congress.

PNL also has an active program with the Historically Black Colleges and Universities (HBCU's). Various HBCU faculty from around the country have spent a day, a week, a month, a semester at PNL. In addition, some of our research programs have subcontracts with individuals at HBCU institutions. In fact, PNL has signed four Memoranda of Understanding with HBCU institutions. We also have initiated an arrangement with HBCU members to support an outstanding student in his/her undergraduate career with a four year scholarship and a research project in the laboratory during each summer. I believe all would agree that we as a country must take advantage of the untapped talent in our traditionally under-represented groups in science such as minorities and women. We must take advantage of all our resources in order to address the global competitiveness challenge.

Not to be overlooked in America's drive to retain its technological strength and regain our competitiveness in global economic markets is the need to do more to stimulate and attract children at an early age to pursue science and engineering as careers. PNL is trying to remedy this situation--at least in our own community and region--with a series of programs that are aimed at challenging youngsters to be the scientists and engineers of the 21st century. Funds for these pre-college programs are included in the Supporting Research budget. While limited, these funds can be characterized as the "seed corn" of our future scientific advancements. These programs are truly aimed at "small" science and deserve increased support from both the government and the private sector.

Also included in the Supporting Research and Technical Analysis budget is a small budget for scientists from industry and laboratories to exchange roles. The national laboratories and private industry need to collaborate more effectively rather than continue the "not invented here" syndrome if America is to succeed in its quest to remain a leader in scientific achievements and be a player in world markets. While the budget to support these kinds of interactions is very limited, it merits your strong support.

Summary

A stable research and development policy and a continuing commitment to basic research are keys to the economic strength of this country. While the U.S. still spends more than any other country on research and development, the percentage of civilian research has remained constant for several years. Meanwhile, our competitors have increased their expenditures for civilian research programs, and are beginning to challenge us in developing new products for export to world markets. For the first time in 1986 the U.S. trade balance in high technology goods was negative.

Basic research is an important investment in our country's future. Just as we learned in the 1970's that oil was an important ingredient to U.S. economic strength, we should be just as mindful that a strong commitment to basic research is an equally important ingredient to our economic strength. The Supporting Research budget of DOE is a vital component of this commitment.

The MSRC Advisory Panel is composed of representatives from National Laboratories, universities, and industry.

Advisory Panel Member	Research Background
Rodney J. Bartlett, Ph.D. University of Florida	Theory and Quantum Mechanics
Robert J. Fletterick, Ph.D. University of California, San Francisco	Structural Biology, Molecular Modeling
Denis Forster, Ph.D. Monsanto Company/St. Louis	Chemistry, Catalysis
Stephen H. Garofalini, Ph.D. Rutgers University	Surface Structure and Dynamics
Jeffrey P. Hay, Ph.D. Los Alamos National Laboratory	Materials by Design
Arthur H. Heuer, Ph.D. Case-Western Reserve University	Ceramic Materials
Marvin L. Poutsma, Ph.D. Oak Ridge National Laboratory	Organic Chemistry
Brian W. Matthews, Ph.D. University of Oregon	Structure of Biological Molecules
Edward M. McCreight, Ph.D. Xerox Corporation, Palo Alto	Computer Systems
John T. Yates, Ph.D. University of Pittsburgh	Surface Science

SUMMARY OF WORKSHOP

In assessing the DOE needs and opportunities for molecular-level research, the working groups found it useful to divide them into four broad classes: the development of new experimental techniques to probe the composition and structure of buried interfaces, the establishment of relationships between the structure and function(s) of such interfaces, the exploitation of advances in computational technology for the presentation and analysis of data, and the development of theoretical models linking molecular-level data with macroscopic-level phenomena. Highlights of the working groups' recommendations in each of these four areas are summarized in this section.

Major contributions of physical science research to DOE applications programs include the invention and development of new experimental probes of composition, structure, and dynamics. Examples of important existing techniques include x-ray crystallography, nuclear magnetic resonance (NMR), optical and electron-beam microscopy, Auger and x-ray photoelectron spectroscopy, and laser pulse-probe techniques based on either Raman or transient absorption spectroscopy. Important opportunities include the molecular-level imaging of living cells and the high-sensitivity in situ spectroscopy of interfaces of interest in both the study of composites and the modeling of environmental processes. New techniques that appear particularly promising are scanning tunneling microscopy (STM) and interface imaging via the exploitation of nonlinear optical phenomena. A major emerging frontier is the study of dynamic processes at interfaces. These can either be used as vehicles for interface characterization (e.g., via the observation of characteristic atomic vibrations) or as important phenomena in their own right in the fabrication and function of interfaces in multicomponent systems.

In addition to a characterization of the composition and structure of interfaces, the utilization of molecular-level information in DOE applications requires an assessment of the relationship between such information and the properties (i.e., functions) of these interfaces. Examples include establishment of the role between protein structure and function, the influence of interfaces on the mechanical properties of composites, and the catalytic effects of trace impurities on environmentally important chemical transformations in soils or aerosols. Studies of the dynamic behavior of molecules at interfaces are particularly important in this context. The demonstration of such relationships requires a felicitous combination of theory and experimental measurement that transcends disciplinary boundaries. Therefore, the working groups recommended that this task be pursued by interdisciplinary teams encompassing efforts from the molecular level to the field level, working together to establish the pertinence of molecular-level processes to field-level phenomena. Molecular-level research is an indispensible part of such an effort, but it must be pursued in concert with more global field-scale research.

A major ingredient of the modern technical scene is the rapidly dropping cost and increasing functionality of computational devices. The working groups suggest that the timely implementation of such capabilities for image processing, real-time data analysis and process control, and the construction of linked microscopic-macroscopic hierarchies of models afford the possibility of quantum leaps in the ability of the DOE to construct quantitative, verified models of the host of biological and environmental phenomena (e.g., biological effects of radiation, toxic waste transport and transformation, and energy flows in the atmosphere) which directly affect its production and regulatory missions. Such implementation also can exert a major impact on the materials options available for the production, conversion, and utilization of energy. One working group envisages a "materials by design" effort in which theoretical models of the atomic geometry and electronic structure of homogeneous materials are combined with modern computing facilities to design composite materials of prescribed properties. Indeed, such already is the case in the design of advanced electronic devices like high electron mobility transistors (Collins 1986). The expansion and diversification of such efforts could have a major impact on U.S. industrial competitiveness by virtue of rendering the fruits of U.S. excellence in basic science directly accessible to its product designers.

Computer technology alone, however, is not enough to ensure the linkage between molecular-level processes and macroscopic-level phenomena. Intellectual invention and innovation also are required. Opportunities include the construction of models describing the functional implementation of genetic information, the description of the intricate feedback systems characteristic of repair and regulatory functions in living systems, the prediction of the mechanical and electrical properties of composites, and the development of linked hierarchical models relating molecular-level information to the transport and transformation pathways characteristic of field-level environmental phenomena. Thus, new theories of complex phenomena embodying multiple time and space scales are required to render molecular-level experimental data pertinent to field-level DOE applications.

The working groups concluded therefore, that a variety of promising opportunities exist for the systematic understanding of molecular-level processes which underlie DOE programs in health, environment, and materials. They further noted that recent advances in computer and communications technologies enable novel institutional approaches to the acquisition of this understanding in a context that renders it directly pertinent to the applications programs. Therefore, the initiation of a broadly based molecular science research effort to serve as a link between university-based fundamental research and national-laboratory-based applications programs would be a timely response to these research opportunities and technological advances. Properly planned and managed, such an effort could serve as a model for integrating the fruits of U.S. excellence in basic research into the solution of the health and environmental problems associated with the production and utilization of energy in the United States during the twenty-first century.

PANEL 1 DISCUSSION

Mr. **Bruce**. Thank you, Dr. Wiley. If I might just ask a few questions and then we will go around. Dr. Zucker, I understand that the High Flux Isotope Reactor is going to be operating at about 85 percent of full power. How does this affect the usefulness of the reactor, particularly as it relates to user activities and isotope production activities?

Dr. **Zucker**. The user activities will just have to be slowed down by about 15 percent and flows directly with the power. The isotope production facilities are for producing heavy elements, and we have devised methods to work around that 15 percent while producing things at the full rate. Other isotopes, medically-important isotopes will go about 15 percent loss.

Mr. **Bruce**. They will be back at full power, when?

Dr. **Zucker**. They will not be back at full power ever. We are going to start off with low power and run the reactor at 85 percent. In 1997 we will have a new reactor.

Mr. **Bruce**. The x-ray lithography initiative, can you comment on how well that is coordinated between the various participants, DOE, and DOD? The Congressional intent was to enhance U.S. semiconductor component markets within four to five years.

Are you going to be able to do that with the kind of cooperation that you see will be needed?

Dr. **Zucker**. Well, I think we have good cooperation between the National Laboratories. We have good cooperation between us and industry, the Oak Ridge National Laboratory and industry. Several industries are coming to the Laboratory to use our surface modification facilities. We have good connections with Sematech, sort of a center of this thing, the semiconductor-industry, research effort.

Sematech, of course, is funded by the Defense Department funds as well as private funding. I would say that everybody is working very hard to make this a unified effort. Like most things that deal with multi-institutional arrangements, there is room for improvement.

I think you better watch it.

Mr. **Bruce**. Are we going to be able to make our intended date of four or five years for improvement?

Dr. **Zucker**. I don't really know. I mean, it is clear that we are making improvements as we go along. We have developed things already in the last year at Oak Ridge which should lead to an improvement. The Laboratories, at least Oak Ridge, is not at the point where these things are turned into devices. We provide the tools.

We are particularly effective, I believe, in developing masks, submicron masks are a very important part of the whole enterprise. We are providing leadership for that activity. We will have those developed but the question is can industry use it. I don't believe that anybody from Sandia is testifying here.

Mr. **Bruce**. Dr. Hartley will be testifying.

Dr. **Zucker**. Oh, yes.

Mr. **Bruce**. Will we beat the Japanese to the marketplace?

Dr. **Zucker**. You have to ask him that. He has a facility that I have seen that I believe is just fantastic. It can beat anybody. It's the cleanest and most modern facility that exists.

Mr. **Bruce**. Thank you, Dr. Zucker. Dr. Schriesheim, I am going to defer at the appropriate time to recognized Mr. Fawell, since the facility is in his District and let him lead off questioning you. The same thing, Dr. Wiley, we will wait until Mr. Morrison is recognized at the appropriate time to ask about your facility located in his District.

We will let you guys off the hook. They actually asked me to let them ask the real tough questions. With that, we will go to Mr. Morrison for questions.

Mr. **Morrison**. Thank you, Mr. Chairman. I am always delighted to ask questions about the Molecular Science Research Center. Dr. Wiley, you talk about small science and perhaps a little more thorough discussion of that is in order. This Subcommittee wrestles with big science, I guess, using your terms.

Do I take it that small science is someone that has an idea that could be perhaps applicable in today's marketplace or is on the verge of a breakthrough in development in competition with the rest of the world; is that what we mean by small science?

Dr. **Wiley**. That could be included. We could say that usually most of the ideas that come out of small science in the invention scale have some commercial applicability, a large fraction of it does. I think what I am meaning here in terms of small science is to distinguish between science of high energy physics and particle physics, astronomy, NASA, big major programs as compared to the work of a condensed matter physicist who works in his laboratory at Harvard, Yale or in our laboratories looking at the surface of materials using frontier level equipment that will result in a publication that has two or three people on it as opposed to high energy physics publication where you might have as many as 100 people working on the same subject and publishing a paper.

Mr. **Morrison**. We are very interested in the things that spinoff the transfer of technology. It appears to me that the molecular science user facility that you have in mind, the commons if we can go back to the previous panel, is very much needed. In fact, it could provide a number of answers that we have been discussing on this Subcommittee.

Obviously, you believe enough in this project that you have invested some funds. Could you reveal to us what your investment has been in this concept over the last couple of years?

Dr. **Wiley**. Over the last couple of years, Congressman, I think that we probably invested upwards of $6 million developing the concept and forming the national committees and review committees and advisory groups, as well as making some investments in starting up what we are calling a structure-function laboratory or looking at macromolecules.

We have made some space in the owned facilities at the Pacific Northwest Laboratory, where we have some of these activities going on already. So, it's about a little over $6 million. By the end of this year, we will probably be at $8 million.

Mr. **Morrison**. You expect by sometime later this year, 1988, that the design will be completed utilizing these dollars?

Dr. **Wiley**. Yes, sir. We intend to complete conceptual design by mid-summer.

Mr. **Morrison**. What are you going to do in 1989 in the fiscal year?

Dr. **Wiley**. Well, as I indicated, we will complete conceptual design in 1988, which means if there were dollars available you could very well begin detailed design of the facility which is a $40 million facility with about $80 million worth of this frontier level equipment and computational capabilities as described.

Mr. **Morrison**. Is there a possibility with the building of some outside funding or third-party arrangements?

Dr. **Wiley**. That is possible for the building. We have every reason to believe that that is possible for the building. However, that leaves us with an $80 million budget for the equipment.

Mr. **Morrison**. I just want to share with the Subcommittee my interest in this. As I have sat through endless hours of hearings this seems to me to be a logical role for taxpayers, all of us collectively, to play in the future of America.

One last question, Bill Wiley. If we help you in funding this project, will you somehow make available to this Subcommittee your secret, award-winning gumbo recipe?

Dr. **Wiley**. Absolutely, Congressman.

Mr. **Morrison**. Thank you, Mr. Chairman. I have no further questions.

Dr. **Wiley**. That's an interesting question. [Laughter.]

Mr. **Bruce**. For the record, we get the gumbo recipe. Mr. Fawell.

Mr. **Fawell**. Thank you, Mr. Chairman. Dr. Schriesheim, I am going to return to my favorite subject of the Advanced Photon Source, and I expect it is high on your list also. In fact, I know that it is.

You referred to an accelerated schedule, and I am somewhat interested in that also. Could you describe this accelerated schedule that you believe ought to be utilized insofar as the construction of the Advanced Photon Source is concerned?

Dr. **Schriesheim**. Yes. We have enough money, if you will, with the $6 million request to do largely paper studies basically in 1989. The $6 million construction and $6.2 million for continuing research and development. Of that $456 million total cost, assuming that it is done in seven years, that is 1996, $100 and some odd million are conventional facilities. By conventional facilities, I mean you have to dig a hole, you have to—that's four football fields—you have to pour concrete and a lot of that has to be done before the internals can be put in place.

So, the increase from $6 million to $20 million in 1989 would get us a long way toward the conventional-facility construction. Then the logical follow on to that are expenditures that would enable the Laboratory to purchase equipment that would go into those conventional facilities earlier in the cycle than we could purchase those if we were on the seven-year cycle.

The accelerated schedule is one that would enable us to construct conventional facilities sooner, purchase the components that need to be put in place in those facilities and, of course, to test the machine. I have such a schedule, and I would be glad, Congressman, to put that schedule in the record.

Mr. **Fawell**. Yes, I would like to have you do so. But are you talking still about a seven year schedule though?

Dr. **Schriesheim**. No. The schedule that is our preferred schedule would start in 1989 and have us finish in 1994, for a cost of $430 million instead of the $456 million, or a savings of $26 million over that span. So we could construct it, instead of a seven and one-half year span, we could construct it in a five-year span.

Mr. **Fawell**. That would be approximately the same, a bit longer than what would be envisioned in Grenoble and also in regard to Japanese schedule to what you mean?

Dr. **Schriesheim**. We would probably hit pretty close to the same time period, considering the testing and start up of the machine. Under any circumstances, it would be a lot closer than the seven and one-half year timespan.

Mr. **Fawell**. I notice that the material science budget within the Basic Energy Science is up about 7 percent. Is this a reasonable increase in your view?

Dr. **Schriesheim**. It's a nice increase but we have to examine what that increase is. About 5 percent of that 7 percent is for facilities, and there is really only a 2 percent increase which is less than inflation, or what I would call the research part—superconductivity, materials science, polymers and so forth.

I think we have a gap, if you will, in that particular budget area.

Mr. **Bruce**. There is an amendment going on in the floor, a Dannemeyer Amendment. We can continue for five more minutes and at the second bell we will suspend the activity here and come back immediately following.

Mr. **Fawell**. Mr. Chairman, I just have one other question that would be posed to actually all three of the witnesses because the technology transfer has been mentioned by Dr. Zucker.

I would wonder in regard to each of your Labs, could you just give a brief summary of technology transfer because I, too, agree that this is something that is so very important. I wonder how much progress we are making.

Dr. **Zucker**. We pay a great deal of attention to that at Oak Ridge. We have a separate group that does nothing but technology transfer of about five people. We have so far licensed 20 of our inventions. In other words, we have 20 licenses now in place.

At the moment, our licensed inventions are about a $10-million business outside the private. These things that we have not licensed that are essentially not patented are the kinds of things that we have invented like a hip joint, much more important in the commercial sense.

We expect in five years to have licenses that are earning about $100 million a year total. We have succeeded in bringing back to the United States, a good fraction of the tool-bit business from Japan. We have returned to the United States I believe from Europe, the heater-wire business, some of the inventions that we have made.

So, I think we have been successful in many cases. But we are not by any means home free. It is very difficult to transfer technology, and it's true that the National Laboratories need to exert our effort. I would like to make one statement to industry and maybe they will listen.

There is one important barrier, the person, an engineer in industry. He wants to make his way to the top of that industry will not take on a technology transfer job. He will not consider this a way of promoting his own status in the industry. I think that has to change. Industry has to regard that as an important activity and reward it accordingly.

I would like to leave that message to whoever wants to promulgate it. That does not exist at the moment. Good people don't do that. Good people have to be engaged in that and we put our best people on that.

Mr. **Fawell**. Dr. Schriesheim.

Dr. **Schriesheim**. I agree with everything that my cohort here, Dr. Zucker said. I don't want to cover the licensing ground once again, but I do want to point out something that is a richness that exists within the National Laboratories. That has to do with the fact that technology transfer is a multi-faceted activity.

The labs are in an almost unique position in this country, having the ability to transfer not only the specific technology in the sense of licenses, but also, information. We transfer information to universities; we transfer information to industry. We run the major user facilities. The Advanced Photon Source will have a consortium of industries that will utilize that facility. In fact, I might just comment that a group of pharmaceutical companies have formed a consortium to develop a memorandum of understanding so they can use that facility.

So the Laboratories represent a whole richness. In thinking about technological transfer from the Laboratories, one has to think of industries putting people in the Lab, of the Lab sending people and the Congress, I believe, needs to make that as easy as possible.

Dr. **Wiley**. Just one statement. We expect to increase our technology transfer through licensing by about 20 different products this year. The important thing is that I think that the National Laboratories represent a mechanism for moving more rapidly from basic science to technology-based businesses. They are spanning a gap between where the university might stop and where industry recognizes it as a business driven basis.

I think those are the key efforts that we are concentrating on, is trying to figure out a way to more rapidly move technology.

Mr. **Bruce**. Thank you. The Committee will stand in recess until 3:15. If this panel would not mind, we would like to reconvene with you because we have further questions of this panel.

[A brief recess was taken.]

Mr. **Valentine** [presiding].

The Subcommittee will please be in order. I recognize Congressman Stallings.

Mr. **Stallings**. Thank you, Mr. Chairman. It is a pleasure, Dr. Schriesheim, to have you here with the Committee. I would just like to make a comment on Argonne and what you are doing particularly in the Idaho operation.

I have had the opportunity for the last three years to work very closely with some of those folks, and have been very impressed with the quality, dedication and the commitment that they demonstrate. I think the Argonne operation has been successful. Sometimes those folks living out in the hinterlands working on the Idaho side are passed over, at least from my point of view are passed over, when it comes to the accolades and compliments for work well done.

I want you to know how impressed I am with the operation there with the commitment, and I think that this year's budget particularly on the IFR demonstrate the kind of work that has been going on out there. I was pleased to see the support that the Department of Energy is giving the IFR this year. It is certainly different than what we went through last year.

Assistant Secretary Garrish testified last week that it is now the principal direction. It's a great line. The principal direction of the Advanced Reactor Program. Argonne is currently doing so very well in extending the national leadership on that and is certainly to be congratulated on this.

You noted that an additional $6 million is needed. Very briefly, why and how much of that would used at the Idaho facility?

Dr. SCHRIESHEIM. The $6 million would be split; $4 million and $2 million, $4 million for the Hot Fuel Examination Facility at Idaho and $2 million for fuel fabrication to produce fuel for FFTF. The total $6 million would be spent in Idaho.

I can't help, even though I am not objective and admit to not being objective, to agreeing with you in terms of the caliper of the people that are located about an hour outside of Idaho Falls. They really are a national asset, a true national asset. We have the only full-scale capability in nuclear power reactors really that exist in this country today. A good fraction of that exists out there in Idaho.

So, it is always a pleasure for me to go there. I will be there this week running program reviews, and I always look forward to the morale, enthusiasm, in addition to going hunting. [Laughter.]

Mr. STALLINGS. We are pleased to have you doing what you are doing at the Idaho facility. I certainly again congratulate you on what you are doing. I think the fact that the Department is now recognizing the value of this new IFR project is really self-explanatory.

Mr. Chairman, that is the only question I had.

Mr. VALENTINE. Thank you, sir. Mr. Hochbrueckner.

Mr. HOCHBRUECKNER. I have no questions, Mr. Chairman.

[Questions and answers for the record follow:]

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

Hearing on the Department of Energy (DOE)
FY 1989 Authorization Request for Supporting Research
and Technical Analysis

Republican Member Questions for the Record
for the Hearing of March 23, 1988, for
DR. ALAN SCHRIESHEIM, DIRECTOR, ARGONNE NATIONAL LABORATORY

1. The FY 1988 Continuing Resolution included $10 million "to initiate a technology program in x-ray lithography aimed at restoring U.S. leadership in the manufacture of high density computer chips." What role, if any, does Argonne National Laboratory have in carrying out this Congressional directive, and how is the implementation of this Congressional directive impacting the base programs in synchrotron radiation at Argonne National Laboratory?

2. What level of funding would you recommend for R&D on high-temperature superconductivity?

3. What is the status of the high-enriched uranium target for the Intense Pulsed Neutron Source at Argonne? When will it be installed, and are the funds requested for FY 1989 allow for sufficient running time so that target will be "self-protecting"?

1. Argonne's contribution to the x-ray lithography initiative coordinated by Brookhaven is principally in providing analytical capabilities of extremely high sensitivity, e.g., SARISA (Surface Analysis by Resonance Ionization of Sputtered Atoms) a technique developed at Argonne, and the capabilities of Argonne's Electron Microscopy Center for Materials Research. By use of SARISA, impurities in semiconductor chips can be detected down to the low parts per billion range (in examining oxides on silicon by SARISA it has been possible to detect the presence of iron at much lower concentrations than ever before). The Electron Microscopy Center provides the capability to identify particulates on semiconductor chips at dimensions down to the nanometer regime and to do analytical work at tens of nanometers. These advanced, highly sensitive basic research analytical capabilities provide the means to study semiconductors and determine what improvements in the manufacturing technology can lead to higher yields and better semiconductors, thus enhancing the competitive position of the U.S. in this area.

The lithography initiative will have no direct impact on the base programs in synchrotron radiation at Argonne. However, the analytical techniques for use at synchrotrons developed by these basic research programs will be applicable in the examination and evaluation of the products of lithography, which in turn will provide the information necessary to the development of improvements in lithographic processes.

2. We would recommend $30M in the DOE Basic Energy Sciences area and $15M in the DOE Conservation area, with a total national commitment by all Federal Agencies of about $150M.

3. The enriched uranium disks for the IPNS booster target have been completed at Y-12 in Oak Ridge. The final assembly and insertion of the target is scheduled for July - August, 1988, with the first beam on target scheduled for the middle to end of August. Funds requested for FY 1989 provide for 23 weeks of IPNS operation, the minimum for the target to remain self-protecting

4/20/88

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

Questions for the Record for the Hearing of March 23, 1988, for Dr. W. R. Wiley, Director, Pacific Northwest Laboratory.

1. *How much in PNL Exploratory Research funds have been committed to date to the Molecular Science Research Center (MSRC)? How much funding is committed this fiscal year, and in FY 1989?*

   Total PNL Exploratory Research funds committed to date: $1,550K

FY 1987	$ 550K
FY 1988	$1,000K
Anticipated FY 1989	$1,200K

2. *When are you proposing a construction start for the MSRC?*

   On the FY 1990 line item schedule, the estimated MSRC construction start date is April, 1991. However, if detailed design begins in FY 1989, construction would begin approximately one year earlier.

3. *What additional funds for the MSRC are you seeking for FY 1989?*

   A request has been submitted for $1M in capital equipment funds for FY 1989 from DOE/BES/Chemical Sciences for initial purchase of leading edge equipment.

4. *What role, if any, might the MSRC have in the project to map the human genome?*

   Two important aspects of the human genome project are the development of new technologies to increase the speed of DNA sequencing and the development of data base management and analysis tools. The basic research in the MSRC will contribute to both these areas. For example, research in the MSRC to develop a new mass spectrometer for application to very large molecules will provide a new detector system for use in DNA sequencing. This basic research will also provide needed information pertaining to large molecule ionization and desorption which will provide a basis for development of new separation and detection schemes for application to the genome. A key factor in the isolation, purification and analysis of the genome is the complication of having to work in aqueous media. Several research projects in the MSRC are targeted at developing a more detailed understanding of the role of water on the interface chemistry of large systems including DNA. These projects include both experimental and theoretical studies.

A significant portion of the research in the MSRC will center on developing new data analysis techniques and procedures which will be directly applicable to the genome project. This includes new ways to link experiment and theory in near real time, new ways to handle very large data sets and new ways to use visualization techniques to assist in the interpretation of large data sets.

PANEL 2: DEPARTMENT OF ENERGY NATIONAL AND SINGLE-PURPOSE LABORATORIES

Mr. VALENTINE. Thank you gentlemen very much. Next is panel number two consisting of Dr. Martin Blume, Deputy Director, Brookhaven National Laboratory; Dr. Danny Hartley, Vice President, Energy Programs at Sandia National Laboratory; and, Dr. Herman Winick, Acting Director, Stanford Synchrotron Radiation Laboratory.

Welcome gentlemen. We will start with Dr. Blume.

STATEMENT OF DR. MARTIN BLUME, DEPUTY DIRECTOR, BROOKHAVEN NATIONAL LABORATORY, UPTON, LONG ISLAND, NY

Dr. BLUME. Thank you, Mr. Chairman. It is a pleasure to testify on the fiscal year 1989 Basic Energy Sciences budget, particularly as it affects Brookhaven National Laboratory.

We have heard quite a bit about proposed new user facilities here as part of the Basic Energy Sciences budget, and we have also heard about technology transfer. I would like to touch in my summary of my testimony on some of these points.

The Basic Energy Sciences budget supports two outstanding facilities at Brookhaven that are already in existence and already in operation. These are the High Flux Beam Reactor which provides very intense beams for sources of neutrons. They are used in very many different disciplines and experiments. And also, the National Synchrotron Light Source, which is a model for several of the new facilities that are to be undertaken.

The programs there cover a very broad range of science and technology and a very broad range as well of users form universities, National Laboratories and from industry particularly. About 80 percent of the users at the National Synchrotron Light Source are from outside of Brookhaven National Laboratory. This facility plays a very large part not just in the research enterprise of the Department of Energy, but on a much broader sense, in the overall national research enterprise.

The areas of science that are studied there are very wide ranging. In particular, at the High Flux Beam Reactor there are important experiments that are elucidating the nature of superconductors that are being done again, not just by Brookhaven scientists but by scientists from Exxon, Bell Laboratories, MIT and from other National Laboratories as well.

It is significant that this testimony is taking place while the American Physical Society is having its annual Solid State Physics meeting this year in New Orleans, Louisiana. This is the first anniversary of the famous Woodstock of Physics meeting that took place last year at which all of the tremendous excitement about superconductivity began at the public eye.

Many of us would like to be there at this time, and in fact, most productive and useful scientists are there. The administrators are left to try to do the best that we can in order to arrange for the funding for the people who are there talking about their results. We are proud that many of the facilities represented here will have scientific results presented at that meeting.

In order to give an idea of the nature of some of these facilities, I would like to make use of the visual aids if I can, and show a few pictures of the National Synchrotron Light Source.

While we are arranging for that, let me just continue discussions. One of the points that have been made is that there is not sufficient funding for the planned new facilities. In fact, what I want to point out is that we also have problems with the existing facilities.

[Slides.]

This is a picture of the storage ring for the National Synchrotron Light Source as it appeared several years ago. You can see the bare elements of the ring and the places where the ultraviolet and soft x-ray radiation come out. Over the succeeding years, there are a series of pictures that I would like to show that will give you an idea of how these have developed.

One of the points that I want to make is that there are tremendous pressures in costs in running these facilities, and in part, these pressures are a consequence of success. This is a picture that was taken just a few years later. All of these pictures are taken from the same vantage point at the ring. You can see the beginnings of the experiments that are placed in here.

There is one point further that I want to make because some of the discussion in the previous panel concerned the difference between large science and small science. It is very important to note that this is collection of many facilities, all of which would be small science in their own institutions.

Indeed, one of the disadvantages of these facilities is that small scientists will have to go to them to make use of these very powerful sources of radiation. This disadvantage, on the other hand, is also an advantage. This is a point that is important in technology transfer. In my view, technology transfer is something that is enhanced by the physical contiguity of people working on different problems.

This is taking place very clearly at the National Synchrotron Light Source, and in fact, interactions between universities and industry scientists have lead to developments that would not otherwise have taken place.

[Slide.]

A few years later as more and more users came along from the same vantage point again, you can see that there are many different and additional experimental beam lines there. In fact, there are researchers at the two facilities, the High Flux Beam Reactor and also the Synchrotron Light Source that come looking around the ring—there's a group from IBM right in front, there's an x-ray lithography from IBM off to the far right.

Bell Laboratories, Exxon and Xerox are all represented with different experimental equipment on the floor, as are researchers from North Carolina State University, the University of Illinois, University of Washington, from the State University of New York at Stoneybrook and many others. I think I have covered just about everyone who is sitting up at the dais at this point. There are others that I could if others were to come into the room.

It is a very impressive collection of researchers from different institutes.

Mr. **Morrison**. How about someone from OMB?

Mr. Blume. The OMB people will only go around and audit, I'm afraid.

[Slide.]

This is the most recent portrait that was taken of the ring. If you look carefully you will see that the walls have been moved back in order to accommodate the increased pressure of the users. This is a consequence of the Phase II program at the Synchrotron Light Source, which allowed us to put extra equipment in and in fact, was strongly pushed by the Department of Energy several years ago.

I believe that this facility and the facility at the High Flux Beam Reactor are cause for pride for Brookhaven, for the Department of Energy and for this Committee for sponsoring it. There has been a tremendous degree of interaction between users from these different disciplines and from different organizations that is very hard to accomplish in any other way.

With that, let me turn to some of the problems that we have. It is very difficult to fund and to operate facilities like this if we have a budget which provides simply for cost-of-living increases each year according to a cost of living formula. The increase in people on the floor that you see over here translates into a need for additional personnel to take care of them, and to additional operating time for the facilities, and into additional upgrades for the equipment so that we can take care of them.

Without that, we are going to be put into something of a dilemma as we have to make very difficult choices between sacrificing operating time and sacrificing research programs. This is the position in which we find ourselves according to the fiscal year 1989 budget. I might add that the same difficulties will occur as the Advanced Light Source at Berkeley come on line, as the Advanced Photon Source at Argonne come on line, and the Advanced Neutron Source.

We, incidentally, are very strongly in favor of rapid construction of those facilities. The point to be made here is that the program is one in which many new opportunities are occurring, and if we are to take care of all of them we have to provide more than a cost of living increase in the funding.

One of the difficulties that we have had, for example, is in the case of the High Flux Beam Reactor. May I have the next slide, please.

[Slide.]

I am showing here the equivalent view of the floor of the High Flux Beam Reactor. It is on some of these spectrometers where beams of neutrons have been used to elucidate the mechanisms of superconductivity in the new High Tc materials. The High Flux Beam Reactor was built in 1966 and was the premier facility in the world at that time for use of neutron beams.

Over the years, however, there has not been ample funding for upgrading the equipment. As you look around here in the foreground, there is a new spectrometer which is a modern state-of-the-art one. All of the remainder of the spectrometers around there are essentially the same type of equipment that was built back in 1966.

In the meantime, a new reactor at the Institut Laue Langevin in Grenoble, France, has come along and they far exceed us, not in the quality of the reactor but in the quality of the experimental equipment that is available. Our own researchers have been hard pressed to keep up with them. They have done this on the very great ability and the proper choice of problems to work on.

We have, over the years, proposed consistently upgrades for equipment, but it has not been possible with the press of new facilities coming along to get this into the budget. In addition, in the fiscal year 1989 budget as proposed, it will only be possible to operate the reactor for three of 11–22 day cycles. We will need an additional $2 million in order to run this for the full period. That means that there will be a large number of experiments that cannot get done.

The new instrument in the foreground was made possible with funds, over $1 million, that came from the Japanese through a United States-Japan treaty. And that is the one way in which we have been able to increase the instrumental capability of the High Flux Beam Reactor.

So this is a problem that exists both at the Synchrotron Light Source, but to a much greater degree at the High Flux Beam Reactor, and we very much hope that we will be able to get the funding so that we are not faced with choices of either cutting off research programs or cutting off operation of these forefront facilities.

We would also like to be in a position to upgrade the instrumentation so that many more sensitive experiments can be done with the facility.

With that, let me turn further to the question of technology transfer and to x-ray lithography. One of the important technological results at the Synchrotron Light Source has been the development of x-ray lithography as a technique for the manufacture of smaller scale computer chips.

This has been done by a group from IBM that put in a beam line back in 1982, and they have worked consistently since then. Could I have the previous slide that will show this.

[Slide.]

There is a beam line in the upper right, a small hutch which is a Class-100 clean room, in which IBM has been making computer chips using the x-ray lithographic techniques. The results have been so promising that now a second facility of this type will be put in at Brookhaven by their East Fishkill Manufacturing Unit. They will use this in testing the actual components.

In order to make x-ray lithography a reality, it will be necessary to have very intense sources of x-ray. The principal mechanism that is available for this right now is synchrotron radiation in a synchrotron radiation source not unlike this but we would like to make one on a smaller scale that would provide the type of x-ray radiation that will make manufacturing a reality.

There are a number of problems with x-ray lithography that previous speakers have alluded to; making of masks, alignment of the masks, steppers and so forth. The problem in which we have become involved at Brookhaven has been the problem of providing a source and providing a U.S.-based manufacturer for such sources.

As a technology transfer exercise, we started two years ago with a series of workshops in which we brought in both computer chip manufacturers and equipment manufacturers for the semiconductor industry. As a consequence of those workshops, we were able to reach a consensus on a national program, a very expensive one a good deal of which would be the responsibility of Sematech.

Congress has provided in the last year for funding for x-ray lithography both in the Department of Energy budget and the Department of Defense Budget. We are still looking to the final determination of the nature of the program that would be underway that we would be able to undertake in order to provide a suitable synchrotron radiation facility for semiconductor manufacturing.

We are very much actively involved in this, and we look to be a major part of the final program that is arranged between the Department of Energy and the Department of Defense.

Finally, I would like to make a few comments about the programs that have been set up by the Department of Energy. We strongly support the development of the new facilities such as the Advanced Light Source at Berkeley, the Advanced Photon Source and the Advanced Neutron Source and, indeed, some of the research and development for the new equipment at the High Flux Beam Reactor at Brookhaven would be very important in leading to the ultimate provision of a source like the Advanced Neutron Source for the 21st century.

However, in looking at the previous reviews such as the Brinkman Panel, the Eisenberger/Knoteck Committee, the Seitz/Eastman Committee and so forth, all of them have made important recommendations and many of these have been followed. However, often overlooked is the fact that among the first recommendations of these panels was adequate funding for upgrading and operation of the existing facilities

I have mentioned that the fiscal year 1989 budget causes difficulties in this regard. Many factors do conspire to increase operating costs, and sometimes as in the case of the High Flux Beam Reactor and the Synchrotron Light Source, this is a consequence of success. The user demand is very high and that means that we need increased staff and more operating time, and we must continue to upgrade these facilities.

The returns from all of these research efforts have been very high, and with continued proper support will, indeed, be even higher. We have heard some of these expectations in discussions of the facilities that are proposed for the future. The work on superconductivity and in x-ray lithography that I referred to is certainly a case in point, and we can expect that there will be many other developments of a similar nature.

Thank you, Mr. Chairman.

[The prepared statement of Dr. Blume follows:]

Testimony of

M. Blume

Deputy Director
Brookhaven National Laboratory
Upton, NY 11973

Before the House Subcommittee
on
Energy Research and Development

BASIC ENERGY SCIENCES PROGRAMS

March 23, 1988

It is a pleasure to testify on the FY 1989 Basic Energy Sciences budget, especially as it affects Brookhaven National Laboratory.

The BES (and RUF) budgets support two outstanding research facilities at Brookhaven; the National Synchrotron Light Source and the High Flux Beam Reactor, as well as important fundamental research programs in chemistry, materials sciences and energy biosciences. Nearly 70% of our BES budget supports the operations of our user facilities. Since about 80% of the users come from universities, industry and other government laboratories, these funds play an important role in the national scientific research and development enterprise, beyond the confines of the DOE internal programs. Our internal research efforts are also broad-based, with an emphasis on research on superconducting materials and on the structure of matter using our major facilities, as well as other research equipment and computational resources.

There have been, in recent years, heavy budgetary pressures on our BES programs. The costs of facility operations increase each year beyond any inflation index, both because of heavy usage by outside scientists (more than 1000 industry and university researchers each year!) and, especially in the case of the High Flux Beam Reactor, because of increased requirements for security and reactor safety.

HIGH FLUX BEAM REACTOR: NEUTRON SCATTERING

I would like to address these problems with specific reference to the neutron scattering research programs at the Brookhaven High

Flux Beam Reactor (HFBR). The HFBR was completed in 1966 and was designed to be one of the world's most powerful sources of neutron beams for research in condensed matter physics, chemistry, biology, nuclear physics and materials science. It began with an excellent, for the time, complement of instruments designed to utilize neutron beams in research.

Over the years many outstanding research results have come from experiments at the HFBR, and it has justified a reputation as one of the most productive neutron beam sources in the world. At present, especially with the High Flux Isotope Reactor at Oak Ridge not operating, it is the most important source of neutron beams in the United States. The results of experiments on new superconducting materials, carried out at the HFBR, are the single most important experiments in elucidating the nature of superconductivity in these materials.

Unfortunately, support for the HFBR is not adequate even for full operation of the facility, much less for upgrading the experimental equipment. The budget for FY 1989 will allow operation for only three of a possible eleven 22-day cycles. In addition, there is no provision for adequate user support or for new instrumentation.

The premiere neutron scattering facility in the world is now the joint British/French/German reactor at the Institut Laue Langevin in Grenoble, France. More funding is available for this single facility than for all U.S. neutron facilities combined. They have far surpassed us in the quality and quantity of the instrumentation available. Our scientists have managed to compete in the scientific research programs only through extraordinary effort and ability.

More than a decade ago, Brookhaven proposed to the Department of Energy construction projects for new instrumentation, so that we could compete with European researchers at the ILL. Our proposals have been reviewed by a series of committees set up by DOE and by the National Academy of Sciences. In each case, the BNL proposal was strongly endorsed. The Seitz-Eastman Committee on Major Facilities for Materials Research and Related Disciplines gave this proposal highest priority for upgrades to existing facilities. More recently, a committee of the Council on Materials Science chaired by P. Pincus strongly endorsed this proposal. In spite of these recommendations, DOE has been unable to accommodate funding in its budget. Neutron scattering is a vital technique in the study of materials. The U.S. must provide not only for a strong research program at present, but also for future facilities. We at Brookhaven strongly support the construction of the proposed Advanced Neutron Source (ANS) at Oak Ridge National Laboratory as a way to give the U.S. leadership in this important technique into the next century. Immediate provision for the Brookhaven proposal will support the U.S. until the ANS comes on line. In addition, construction of these new instruments will provide a needed R&D base for the equipment to be built at the ANS. An additional $3 million in operating funds will be needed for proper operation of the HFBR in FY 1989 and for adequate support for user programs. The neutron beam lines and facilities upgrade project will require a total of $25.7 million over a four-year period. We have carried out fully the advance work necessary for our proposal and are ready to begin construction.

NATIONAL SYNCHROTRON LIGHT SOURCE: X-RAY LITHOGRAPHY

The National Synchrotron Light Source is the country's major source of ultra-violet light and x-rays for experiments in condensed matter physics, materials science, chemistry, biology, medicine and technology. Experimenters from more than 100 universities, industrial organizations and government laboratories make use of these research facilities. The NSLS x-ray ring is just coming back from a shutdown during which major modifications have been made to the ring to enhance the brightness of the beams. In addition, some much needed additional space has been constructed as part of the "Phase II" project. The proposed budget for FY 1989 does not provide adequately for the additional power costs of operating the rings, nor does it allow us to expand the services available to the increased user community. A further major problem is a cut in the accelerator improvement program funds available to the NSLS for upgrading the storage rings and increasing their reliability. These funds will go from $2 million in FY 1988 to $1.25 million in FY 1989. This will cause serious delays in several important upgrade projects.

One of the important technological results at NSLS has been the development of x-ray lithography as a technique for the manufacture of smaller-scale computer chips. Since 1982 IBM has had a research program at the UV ring, which has performed very successfully in the development of x-ray lithography techniques. Indeed, IBM has recently asked for and received approval for a second facility, to be provided by their East Fishkill Manufacturing unit, to test the production aspects of these techniques. A significant component of an x-ray lithography manufacturing plant will be an x-ray source: a synchrotron radiation facility designed explicitly for such manufacturing. German and Japanese manufacturers have strenuous development programs underway to produce such sources. The Japanese, for example, have as many as 10 different prototype machines under development. Beginning two years ago, Brookhaven undertook, as a Technology Transfer effort, a series of workshops on x-ray lithography with special reference to the development of a U.S. manufactured synchrotron radiation lithography source. A national program has been outlined, with extensive participation by U.S. industry, for a program leading to a U.S.-based x-ray lithography capability. Brookhaven, in particular, with its strong expertise in synchrotron radiation sources, has offered to take the lead in the development of such sources. The proposed program involved the design and construction of a prototype 1 GeV conventional synchrotron source, together with a 1 GeV linear accelerator injector, as well as the development of a "compact" superconducting source. While the U.S. has not yet agreed on nor funded this program for a synchrotron source, the Japanese have adopted both parts of our plan. In particular, they are building the prototype conventional 1 GeV synchrotron and injector as their primary thrust.

The Department of Defense and the Department of Energy have indicated support for some aspects of this program. At Brookhaven, an important contribution to a national program is the continuing operation of the UV ring so that the IBM experiments, the results of which they have offered to share with the U.S. semiconductor industry, can continue at a rapid pace. We are strongly committed to assisting in this national effort, and we hope to see a coherent program emerge.

CONCLUSION:

A series of reviews of research facilities (e.g. Brinkman Panel, Eisenberger/Knotek Committee, Seitz/Eastman Committee, etc.) have made important recommendations, some of which have been followed, concerning new projects. We are pleased that, in the BES budget, the Advanced Light Source has begun construction, that the Advanced Photon Source is proposed in FY 1989 for funding, and that the Advanced Neutron Source has been given R&D funds leading to a construction start in one or two years. Often overlooked, however, are the strong recommendations of these panels for adequate funding for operation and upgrading of existing facilities. The FY 1989 budget illustrates the difficulties that are caused by ignoring these recommendations. A sound national program requires that we keep existing forefront facilities operating at the best possible level, with due attention to the fact that their budgets cannot be dealt with by formula "cost-of-living" increases. Many factors conspire to increase operating costs. Sometimes, as in the case of HFBR and NSLS, this is a consequence in part of success: user demand is very high, leading to pressures for increased staff and more operating time. These devices are also dynamic - they must be maintained, improved and upgraded to realize their full potential (and, incidentally, to keep them competitive with facilities built later abroad with what seems to us to be lavish funding). The returns from these research efforts have been high and will, with continued proper support, be even higher. The work on superconductivity and on x-ray lithography referred to above are but two cases in point.

Biographical Data

Martin Blume is Deputy Director of Brookhaven National Laboratory, Upton, NY. He received his bachelor's degree from Princeton and his Ph.D. in theoretical physics from Harvard. He has been at Brookhaven since 1962 and was appointed Deputy Director in 1984. He is a member of the Committee on Materials Science and Engineering, which is preparing a report on the status of Materials Science and Engineering in the United States. He received the E.O. Lawrence Award for physics in 1981 for his research in theoretical solid state physics.

STATEMENT OF DR. DANNY L. HARTLEY, VICE PRESIDENT, ENERGY PROGRAMS, SANDIA NATIONAL LABORATORIES, ALBUQUERQUE, NM

Dr. **Hartley**. Thank you, Mr. Chairman. Our energy programs involve approximately 1,000 FTE's at Sandia out of our total of 8,250 people. Although we are generally considered to be a defense lab, I am sure that you will agree that a commitment of 1,000 quality recruited scientists, engineers and support staff is a significant commitment to energy programs.

Our energy programs also cover the gamut from BES to fossil conservation, nuclear waste disposal, renewables and solar. Because of our Bell Laboratories ethos and our Bell Labs leadership, we built our energy programs in a coordinate, mission oriented way. We find a central theme and we build on our strengths around that theme. This has been especially true for our BES programs.

As a result, we found our niche with BES in material sciences and chemical sciences and geosciences and in applied math. These have been world class activities that we are very proud of, and much of the scientific product has moved through technology programs at Sandia and have been subsequently transferred to industry.

The material sciences are focused on scientifically tailored materials. This award-winning talent combines our skills in solid state sciences, atomic level diagnostics, and materials processing sciences to produce new, tailored materials for the U.S. energy industry, the electronics industry and for defense.

Sandia's strained-layer superlattice technology, for example, has already been applied at companies such as Hughes Aircraft and Northrup Corporation. Superlattice has also promised to provide the basis for photovoltaic cells with sunlight conversion conversion efficiency of over 30 percent.

Two weeks ago we also announced our success in synthesizing a new thallium-containing ceramic superconductor which loses its resistivity at 120 degrees. This is significantly above the nominal 90 degree barrier that was announced recently by several other researchers.

To enhance even more our technology transfer efforts in the materials science area, we will be relocating much of our BES materials program into a new building, the Integrated Materials Research Laboratory which is being funded by the Defense Programs. This facility is adjacent to our Integrated Circuit Research Laboratory that Dr. Zucker referred to earlier as such a beautiful, magnificent facility. The combination of those facilities we will be using to form a microelectronics research park so industries can have access to those terrific facilities.

Incidentally, the clean-room technology that all of that is built on was an invention of Sandia Laboratories a few decades ago.

In chemical sciences, our entire focus is on combustion science in our Combustion Research Facility, the CRF, at Sandia-Livermore. This facility applies advanced methods, lasers, computers, to solve energy-related combustion problems. Over 90 percent of our energy and virtually all of our air pollution comes through a combustion process and those are typically 1950's technology. It shouldn't be surprising that industry worldwide is recognizing the need for improved combustion science.

The CRF has become pre-eminent in that field, yet it is relatively small. Only 40 professional staff are at Sandia. During 1988 we will have over 850 scientists join us in research at the CRF; 75 of those are long-term resident scientists from outside including representatives from General Motors, Ford, Chrysler, Cummins, Navistar, Exxon, Unocal, General Electric, Weyerhaeuser, and Lennox, to give you a few examples, and from several universities all across the United States.

In addition to helping industry with many of their specific problems, CRF staff discovered a remarkable chemical process called RAPRENOx for removing nitrogen Oxides from combustion gases. This discovery has received worldwide acclaim, and the inventor has set up his own business with major industry support to commercialize the process.

In the case of RAPRENOx, BES supported the fundamental work leading to its discovery, and the DOE conservation engine combustion program, colocated at the CRF, supported the developmental studies in research engines that created a level of confidence that attracted the industry funding.

Mr. VALENTINE. Dr. Hartley, let me just ask you if you will suspend for a few minutes. We must be getting close to 10 minutes—we have a vote. I apologize for that, but if we don't go over and vote when we have the opportunity some folks will hold that against us.

Dr. HARTLEY. I understand.

Mr. VALENTINE. We will be back in a few minutes.

[A brief recess was taken.]

Mr. VALENTINE. The Subcommittee will come to order. Before we get far into the testimony Mr. Morrison will be along soon. Dr. Hartley, will you proceed.

Dr. HARTLEY. Thank you, Mr. Chairman. I hope that you will take my word for it that I have managed to convince you of the wonderful science that we are doing in materials and in the combustion area with a considerable amount of technology transfer.

When we had to discontinue, I was discussing our Combustion Research Facility at Livermore, which is a true paradigm of a valuable energy-related user facility in this country. In order to maintain our leadership role in combustion and meet our DOE program needs, we ask that our construction project, which is CRF Phase II in the budget be carried to completion.

CRF II was proposed to DOE in 1984. DOE had it as high priority including cross-office support from managers in fossil energy and conservation as well as BES. We also received extensive peer review and peer endorsement in 1986, and have been funded in fiscal year 1987 and 1988 by Congressional initiative.

Our geoscience program is, in many ways, similar to our combustion program. You combine a solid BES-supported program in geosciences with major geotechnical responsibilities for many DOE program areas. Characterization of the Strategic Petroleum Reserve, geotechnical evaluations of both the defense and commercial nuclear waste repositories, seismic verification technologies for defense and lead geoscience roles in geothermal, oil, oil shale and gas programs.

Technology transfer accomplishments abound in our geoscience and our geotechnology programs. A few recent examples are a downhole seismic source and an anelastic strain recovery system that were developed by BES geophysics sponsorship at Sandia and were first fielded by our DOE geotechnology programs with fossil energy and with renewables. These are now being used successfully in joint programs with industry, for example, Amoco, Phillips and British Petroleum. To enhance the vital linkage between geoscience and geotechnology, we have recommended to DOE a Geoscience Research Park in Sandia-Albuquerque. This user facility, operated like the CRF, has been submitted as an Office of Energy Research-funded facility.

The initial phase is a Geoscience Research Laboratory an Simulation Facility that would unite our efforts and make these accessible to visiting scientists.

Finally, our efforts in mathematics for BES are young, but have focused on massively parallel computation. Last week we announced our significant accomplishment in running a custom built parallel system composed of 1,024 processors. We achieved a computational speed up of over 1,000 which allowed this small system to out perform the latest supercomputers at one-tenth the cost.

In summary, we believe that our BES programs have benefitted from Sandia's management style, our high quality staff, from our mission orientation. Our facilities, both existing and planned, are designed to advance science, make an impact in their field, get the results to industry and to improve our linkage with our peer community.

We hope that you will continue to support these efforts. Thank you, Mr. Chairman.

[The prepared statement of Dr. Hartley follows:]

The Value of Basic Energy Science in the National Laboratories

Submitted to:

The Subcommittee on Energy Research and Development
of the
House Science, Space and Technology Committee
The Honorable Marilyn Lloyd, Chairwoman

Submitted by:

Danny L. Hartley, Vice President
Energy Programs
SANDIA NATIONAL LABORATORIES
Albuquerque, New Mexico

March 23, 1988

THE VALUE OF BASIC ENERGY SCIENCE
IN THE NATIONAL LABORATORIES

Introduction

Thank you for inviting Sandia National Laboratories to describe our activities supported by the Department of Energy's Office of Basic Energy Sciences, to review for you recent scientific accomplishments, and to describe how these accomplishments have been translated into technological value. Our activities in Basic Energy Sciences are grouped into four leading-edge research efforts. Research in the **material sciences** includes: scientifically tailored materials, strained layer superlattices, high temperature superconductors and ceramics. Our work in the **chemical sciences** centers on combustion research at the Combustion Research Facility at our Livermore site. We also have an integrated **geosciences** research effort which supports investigations in geomechanics, geochemistry, and geophysics. A growing area of research is that of **applied mathematical sciences**.

The scientific investigations in each of these areas are designed such that the acquired understanding has high relevance to well defined technological issues and opportunities. Today I will present a number of examples which illustrate both the process by which we cooperate with universities and industry and the high, observable value of recent accomplishments.

Materials Science

Our award-winning Scientifically Tailored Materials project is a rapidly growing part of the Basic Energy Science effort. Its major objective is to combine Sandia's expertise and capabilities in the areas of solid state sciences, advanced atomic-level diagnostics, and materials-processing science to produce new classes of tailorable materials for the U.S. energy industry, the electronics industry and for defense needs. Recent work on compound-semiconductor strained-layer superlattices is just one example of a number of interdisciplinary projects. These man-made high-quality crystalline materials represent new classes of materials that have never existed before and exhibit electronic, optical, and catalytic properties that are both entirely different from those of their constituent materials and not present in bulk form. At Sandia we have applied these new materials in our nuclear weapons programs for the development of unique high-speed field-effect transistors, optoelectronic emitters, and detectors. Likewise, these materials promise to provide the basis for photovoltaic cells with sunlight conversion efficiencies over 30 percent. Applications of our strained-layer superlattice technology have already occurred at companies such as Hughes Aircraft and Northrup Corporation.

Sandia is currently conducting an integrated research effort aimed at understanding the physics, physical properties, and synthesis procedures of copper oxide based high temperature superconductors. Newly discovered inorganic superconductors with high transition temperatures have vast technological potential, and the origins and nature of their superconductivity are vital issues. With our existing capabilities, we are making significant contributions to the understanding, development, and application of these materials. Most recently we have synthesized a new thallium-containing ceramic superconductor, which loses its electrical resistivity at 120° Kelvin (minus 243° Fahrenheit). This critical temperature is significantly above the nominal 90° Kelvin critical temperature exhibited by many of the recently announced high temperature superconducting materials and provides a significant operating margin over liquid nitrogen temperatures of 77° Kelvin. More details of this recent discovery are provided in attachment 1.

In addition to our experimental research, we have developed a unique, theoretical picture in which high temperature superconductivity is explained by complex, but coherent, superpositions of spin orbital configurations. This theory accounts for the special nature of copper oxide sheets in all of the high critical current superconductors.

Ceramic material fabrication techniques, using solution chemistry and hot-pressing techniques, have allowed preparation of samples in single crystal, bulk ceramic, tape, and thin film forms. We believe that our materials technology has progressed to the stage that it is possible to make materials into the basic forms required for device application. We are therefore initiating an effort on device technology development that will attempt to apply these research results to potential early applications of high temperature superconductors in electric power systems and advanced energy technologies. This is but one example of how the understandings developed in the Basic Energy Science program are linked with advanced technology development sponsored by the DOE Renewable Energy Office.

To provide further synergism with our established, broad materials responsibilities for DOE Defense Programs, we will be relocating most of our BES materials research into the Integrated Materials Research Laboratory, funded by DOE Defense Programs. Colocation of these efforts in a modern, accessible laboratory will contribute even further to our technology transfer goals.

Combustion Science

Sandia's Combustion Research Facility (CRF) applies advanced capabilities in lasers and computers to combustion science and technology. Designated as a "User Facility", the charter of the Facility is to develop and maintain special-purpose resources to support a nationwide initiative -- involving U.S. universities, industry, and national laboratories -- to improve our understanding and control of combustion. Today resources are diverse and include specialized lasers, computers, and more than two dozen laboratories optimized for the study of combustion-related research activities involving individual or small collaborative groups of researchers.

To promote the use of the CRF as a User Facility, we maintain an aggressive Visiting Scientist Program from universities, industry, government organizations, and other national laboratories to work closely with the resident staff of approximately 40 Sandia professionals. During 1988 we anticipate a total of approximately 850 scientists will join us in the research activities at this facility. Approximately 75 of this total will be long term guest scientists, primarily from universities across the U.S. In addition, industrial participation includes representatives from General Motors, Ford, Chrysler, Cummins, Navistar, Exxon, Unocal, General Electric, Lennox, Toshiba, Hitachi, and Institute Francaise de Petrol. More details concerning the CRF and its accomplishments, both scientifically and in technology transfer, are presented in attachment 2.

An example of recent research, which has been widely recognized, has resulted in the invention of a process that removes practically all nitrogen oxides, a major pollutant, from combustion exhausts. This process, called RAPRENOx for RAPid REduction of Nitrogen OXides, also has the potential for preventing the formation of soot without increasing nitrogen oxide, a limitation in current soot-control processes. The inventor and former CRF scientist, Dr. Robert Perry, has formed a new small business named Technor and is in the process of commercializing the process for application to diesel engine and other industrially significant systems. The colocation at the CRF of BES chemical sciences (which supported the basic work leading to RAPRENOx) and Conservation's Engine Combustion Program (which supported the developmental studies of RAPRENOx in engines) allowed rapid transfer of this from discovery to a level of confidence that attracted industry.

In order to maintain the technological superiority of this national facility and to more completely support the ongoing applications of combustion science to DOE program needs and industry partnerships, a Combustion Research Facility Phase II proposal was developed. CRF Phase II was proposed to DOE in 1984 and received high priority status within DOE, including cross-office support from program managers in Fossil Energy and Conservation as well as BES. It received peer review and endorsement in 1986 by an extensive user review committee (chaired by Dr. James Kane, former Deputy Director, Office of Energy Research). This new phase will increase laboratory space, add next-generation laser diagnostic capabilities, and greatly improve supercomputer access within the entire facility. Funding of $300 K was received for this initiative in FY1987 for design with subsequent construction funding of $4.5 M provided in FY1988. Additional construction funding of $9.7 M is needed in FY1989 to allow completion by the anticipated date in FY1992 (TEC $18.9 M).

Geoscience Research

Our geosciences activities involve research in geophysics, geomechanics, and geochemistry. Our long-term objective is to generate an understanding of active geological processes in order to predict their impact on projects such as resource recovery, waste disposal, and seismic prediction. The role of mass, energy, and momentum transport in the study of active volcanic and tectonic processes is one fundamental theme, and the integration of laboratory studies, field data, and computational modeling is key to our approach. The Continental Scientific Drilling Program (CSDP) is a vital element of the program because it provides an opportunity for direct observation of processes, rocks, and minerals of the earth's crust. Our role in CSDP involves generic and site-specific research as well as implementation of the DOE part of the CSDP through the Geoscience Research Drilling Office at our Albuquerque location.

Emphasis in the geoscience area is expanding to include a larger effort involving measurement and interpretation of transport processes in oil and gas reservoirs. As an example of technical progress in this area, a new down-hole, swept-frequency seismic source has been developed and made available to those involved with petroleum exploration and production during the past year. Also, an innovative technique for obtaining in situ stress characteristics by measuring the anelastic recovery of strain on recovered cores from wells has been developed and used successfully in joint programs with Amoco, Phillips and British Petroleum during 1987. In both cases, the scientific principals and materials technologies were derived from Basic Energy Science programs, then were rapidly fielded in geotechnical applications sponsored by DOE Fossil Energy and by geothermal applications for DOE Renewables. As with the CRF example above, the colocation of these basic and applied programs at Sandia greatly accelerated technology transfer.

Sandia also has major geotechnical responsibilities for many DOE programs; reservoir characterization in the Strategic Petroleum Reserve, geotechnical evaluations for the Waste Isolation Pilot Plant (WIPP) and for the Commercial Nuclear Waste Repository in Nevada, seismic studies for nuclear treaty verification, in addition to our lead geoscience roles in geothermal, oil and gas and Continental Scientific Drilling.

To enhance the vital linkage between geoscience, geoengineering and the related disciplines, a Geoscience Research Park at Sandia National Laboratories in Albuquerque has been recommended. This facility -- operated as a National Users Facility for scientists and engineers from universities, industrial organizations, state organizations, and other federal laboratories -- has been recommended to DOE as an Energy Research funded facility. The initial phase of this park would be a $19 million Geoscience Research Laboratory and Simulation Facility that would unify efforts among basic and applied research, advanced development, and engineering development to attack problems of energy and minerals supply, waste disposal, water resource protection, and seismic prediction. Value would be observed from this facility in much the same way as at the Combustion Research Facility in Livermore, CA. More details about the Geoscience Research Park are presented in attachment 3.

Applied Mathematical Sciences

Our research emphasis in computational mathematics has been focused on the development of algorithms to take advantage of massively parallel computers. Massively parallel solutions to large, highly structured, linear algebraic systems are important to DOE problems such as fluid and plasma dynamics, structural mechanics, combustion, and materials science. Just this month Sandia scientists have demonstrated the ability to increase the speed at which complex, real-world problems can be solved in almost direct proportion to the number of processors in the machine.

A custom-built parallel processor composed of 1024 processors, each with the processing capability of Digital Equipment's popular VAX 11/780, achieved "speedups" of over 1000 on three different types of problems. This allowed the small machine to meet or beat the best performance of the latest supercomputers at about one-tenth the machine cost. Future research in this area should continue to expand on this accomplishment.

Summary

In summary, we continue to find the Basic Energy Sciences to be a rich field which is yielding major technological value in areas of pressing national importance. The facilities which have been developed at Sandia and are planned for construction, specifically the completion of CRF Phase II and the initiation of the Geosciences Research Park, are providing and will provide unique centers for improved alliances among the universities, national laboratories, and industry research units. These collective activities also provide the important linkage between the more basic research programs and the more applied technology activities; this results in the most efficient development, transfer, and commercialization of technology and helps to maintain U.S. competitiveness in the world market.

Attachment 1

SANDIA HIGH TEMPERATURE SUPERCONDUCTIVITY PROGRAM

Sandia is conducting an integrated research and development program aimed at superior knowledge concerning the synthesis, physical properties, and physics of copper oxide based high temperature superconductors. Our technology targets are to develop processing for optimum materials properties and to identify device applications of interest to the Department of Energy.

Newly discovered inorganic superconductors with high transition temperatures have vast technological potential, and the origins and nature of their superconductivity are vital issues. With our existing capabilities, we are making significant contributions to the understanding, development, and application of these materials. Most recently we synthesized a new thallium-containing ceramic superconductor, which loses its electrical resistivity at 120 degrees Kelvin. We have made widely recognized contributions concerning this important material's synthesis, structure, composition, magnetic and electrical characteristics. We were first to disclose the processing protocol, composition and critical current characteristics. Our material is predominantly single phase with zero resistance above 120°K. This critical temperature is significantly above the nominal 90°K YBaCuO materials and thus the characteristics at liquid nitrogen temperatures (77°K) and operating margin are greatly enhanced over previous material.

The three major challenges in conquering and then applying copper oxide based superconductors are: 1) improved processing to enhance bulk properties, particularly critical current J_c; 2) increased fundamental materials understanding; and 3) increased critical temperature T_c. Our studies address all three. We have shown the importance of intergranular interconnects and Josephson junctions in bulk $YBa_2Cu_3O_{6.9}$ ("1-2-3" material) and we have demonstrated improved properties with various processing protocols. By use of a unique high pressure oxygen system we were the first to make bulk superconducting La_2CuO_4 and presented the first evidence that it is a superconducting superoxide. The same high pressure oxygen system has been used to make crystals of 1-2-3 material (grown both at Sandia and AT&T Bell Laboratories) fully superconducting.

We developed a unique theoretical picture in which the carriers are "spin hybrids," i.e., complex but coherent superpositions of spin orbital configurations. A spin-deviation component is responsible for the high temperature superconductivity. This theory accounts for the special nature of the CuO_2 sheets in all of these high T_c superconductors.

More details about some recent Sandia superconducting successes follow:

I. High Pressure/High Temperature Oxygen Preparation of Superconductors

We constructed a unique high pressure high temperature oxygen system to process high temperature copper oxide based superconductors. We showed that the prototypical precursor material La_2CuO_4, which is an antiferromagnetic insulator, can be turned into a bulk superconductor with a transition near 30K by annealing at 3000 atmospheres of oxygen pressure at 600K for about 12 hours. Our studies indicate that the additional oxygen incorporated is the superoxide (an oxygen molecule with a single negative charge). This unexpected result may have important implications for oxide superconductors in general since this is the simplest system yet found. It lends itself best to conceptual and theoretical modeling.

Active collaborations are ongoing with Los Alamos, Argonne National Laboratory, University of Florida, and AT&T Bell Labs on these high pressure oxygen treated materials. This technology is being transferred to several laboratories including General Electric, BTL, Lawrence Berkeley, and Lawrence Livermore, and representatives of several of these laboratories have visited Sandia.

II. Chemically Prepared High Critical Temperature Superconductors

Superconducting ceramics such as $YBa_2Cu_3O_{7-x}$ have received worldwide attention since they can have critical temperatures (T_c) above that of liquid nitrogen. Unfortunately, it has been extremely difficult to fabricate the high T_c materials into shapes convenient for device applications without destroying the desired superconducting properties. We are developing chemical fabrication techniques that will be easier, cheaper, and more amenable for device fabrication than existing techniques such as molecular beam epitaxy. The work focuses on preparing precipitates of hydroxycarbonate precursor powders, which are then heat treated to make the superconducting oxides. We use the precursors to fabricate thin films (via spin or dip coating), lines for interconnects (via ink-jet printing), and bulk ceramics (via sintering of pressed pellets). To date, the best Sandia materials exhibit a T_c of 92K, the highest reported critical current (1320 A/cm^2 at 77°K) for chem-prep superconductors, and (for chloride doped material) extremely high flux pinning.

In situ Raman scattering diagnostics have been used to determine the phases formed in Y-Ba-Cu-O high temperature superconductor processing as a function of processing conditions and surface preparation techniques. Sensitivity to the near-surface region and to common impurity phases make this technique particularly valuable, displaying rapid and reversible changes in the ceramic structure over selected processing conditions, as well as substantial phase changes induced by fracturing or sawing the bulk material. Additionally, we are studying the relationship of the superconducting ceramic morphology and chemistry to magnetic flux exclusion and pinning on the microscopic scale. We are using a decoration technique widely applied to metal superconductors combined with other analytical probes, and have found great variability in morphology and decoration behavior between different fabrication processes as well as between different lots made by a given process.

III. Critical Current and Grain Decoupling

The current-carrying capacity (critical current density) of a superconductor is commonly the limiting factor on its utility for Sandia application~~s~~ such as a fast-opening switch for pulsed power and a high velocity superconducting projectile used in a magnetic "reconnection" gun. It is particularly crucial to optimize the critical current density as a function of both temperature and magnetic field. This requires an understanding of the mechanisms determining the critical current density in a given material. So far we know that the supercurrent in the ceramic materials is severely limited by intergranular Josephson junctions, particularly in a magnetic field. The rapidly falling critical current density in a field causes a low-field transition, first identified at Sandia, to decoupled magnetic behavior of the grains in the ceramic. Recognition of this decoupling led to identification of large intragranular critical current densities from magnetization measurements. This proved that no intrinsic barrier to achieving high current capacities exists in these materials. We have improved the critical current via more intimate intergranular contacts (grain alignment, clean grain boundaries, elimination of voids).

Another potential avenue to higher critical currents is opening with the confirmed discovery of materials with higher T_c. In general, the further below T_c the operating temperature is, the better the operating characteristics. This is borne out in the newly discovered 120K superconducting thallium compound whose composition and characteristics were first disclosed by

Sandia. Critical currents at liquid nitrogen temperature (76K) are comparable to our best 90K ceramics. Considering that our preliminary samples are highly porous and contain at least 40% nonsuperconducting phases, these results are highly promising.

IV. Theory of High Temperature Superconductors

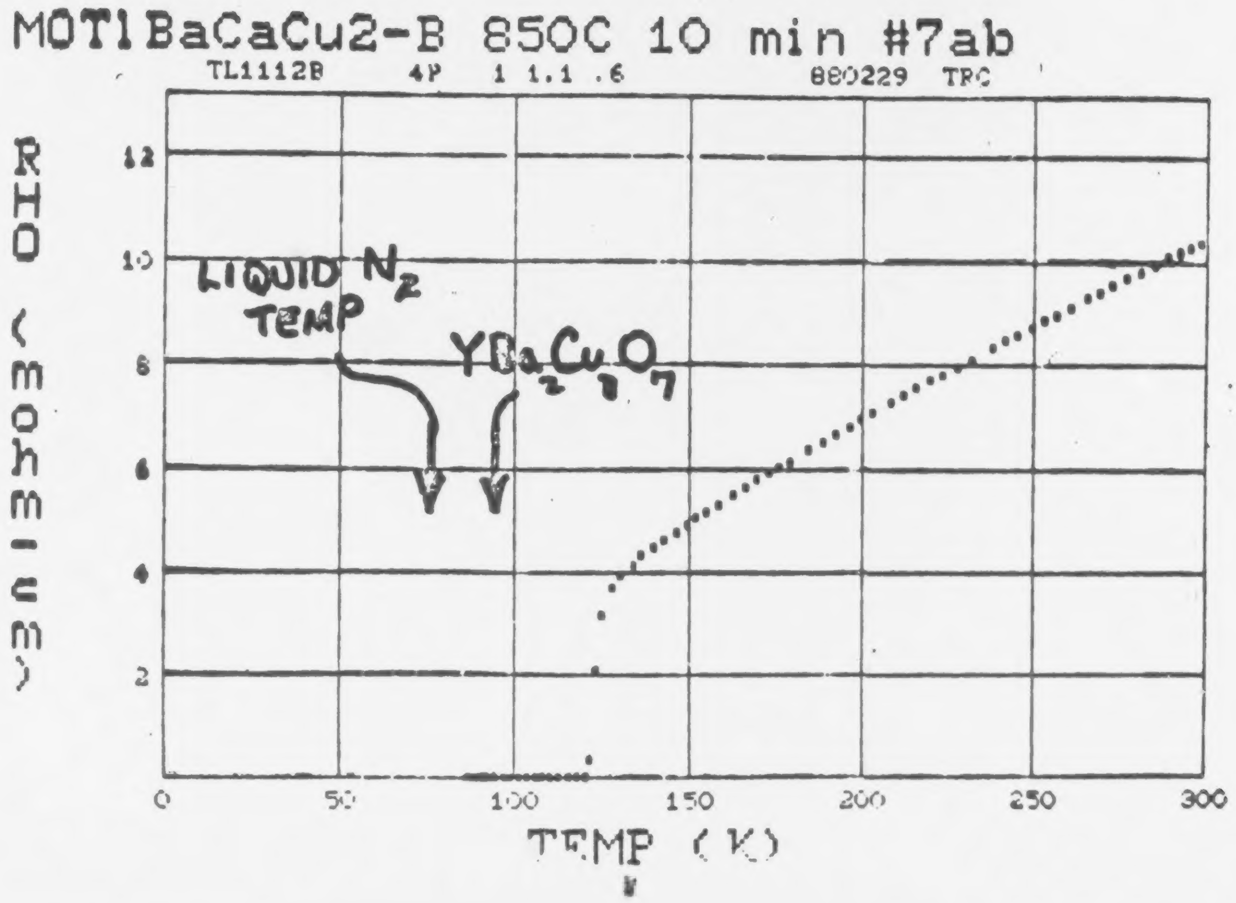
We completed an extensive study of the unique electronic structure of CuO_2 sheets, which are common to all high temperature superconductors. Our work paints a complete theoretical picture: we determined the values of the relevant energy parameters and used these to create a model which contains the essential physics. This model - in agreement with recent experimental observation - predicts that a spin system exists in these materials even in the presence of charge carriers. The model also predicts unusually strong coupling between the charge carriers and the spin system which results in a high probability of finding mobile charge carriers in association with deviations from the locally preferred spin order. There are several reasons for the strong coupling, including the facts that copper atoms can rather easily change their valency from Cu^{++} to Cu^{+} when a charge carrier is close by and that deviations from the local spin order can be easily made (a fact that is not true if one substitutes a higher spin transition metal ion for copper). The unique character of the charge carriers prompted us to name them "spin-hybrids." They do not carry their spin-deviations with them as they move, since on a very fast time scale they can heal deviations which they have created; thus they are not spin "polarons," nor do they move as bosons which then could condense to produce superconductivity. These conclusions separate us from the work of others.

The charge carriers form copper-like pairs by exchanging spin excitations and by attractive interactions between their spin excitations. Due to their spin-hybrid nature, these purely electronic pairings are strong. Of the above conclusions we are quite certain. However, this may not be enough for superconductivity because these interactions are confined to a two dimensional sheet which by itself would typically exhibit a superconducting phase transition only at $T = 0$. We hypothesize that the value of T_c is determined not only by the strength of the spin-driven pairings with the CuO_2 sheets but also by the strength of Josephson tunneling of pairs of carriers between the sheets. This concept is currently undergoing further investigation.

V. A 120K Bulk Superconductor: $(Tl_{.33}Ba_{.33}Ca_{.33})_3Cu_2O_x$

We reported initial findings on the superconducting system containing thallium, barium, calcium, copper and oxygen. Using mixed oxides with a stoichiometry of either $TlBaCaCu_2O_x$ or $Tl_2BaCaCu_2O_x$, we made a bulk ceramic material with a single superconducting phase that shows both a diamagnetic (Meissner) and resistive onset above 120K and zero resistance as high as 120K. The Meissner signal is constant below 100K and its magnitude indicates that at least 60% of the material is superconducting. Preliminary critical current measurements show over 1000 A/cm^2 at 76K for 50% dense ceramic material, which is as high as that measured in good quality ceramic $YBa_2Cu_3O_{6.9}$.

The material is synthesized by briefly sintering the starting compositions at 850°C in air for 10 minutes. Thallium forms a liquid that aids in synthesis. The best superconducting results are obtained by then oxygen annealing the air sintered material for 12 hours with a slow cool at 850°C and 1 atm. of oxygen. Structural and compositional analyses show that the superconducting phase is approximately $(Tl_{.33}Ba_{.33}Ca_{.33})_3Cu_2O_x$ and that the Ba and Ca sites are interchangeable and the relative occupancy affects T_c. The structure has a tetragonal unit cell with a = b = 3. 840 Angstroms and c = 19.72 Angstroms. The structural type is similar to that for the extended perovskite $La_{2-x}A_{1+x}Cu_2O_{6-x/2}$ with A = Ca, Ba, or Sr, but of a lower symmetry.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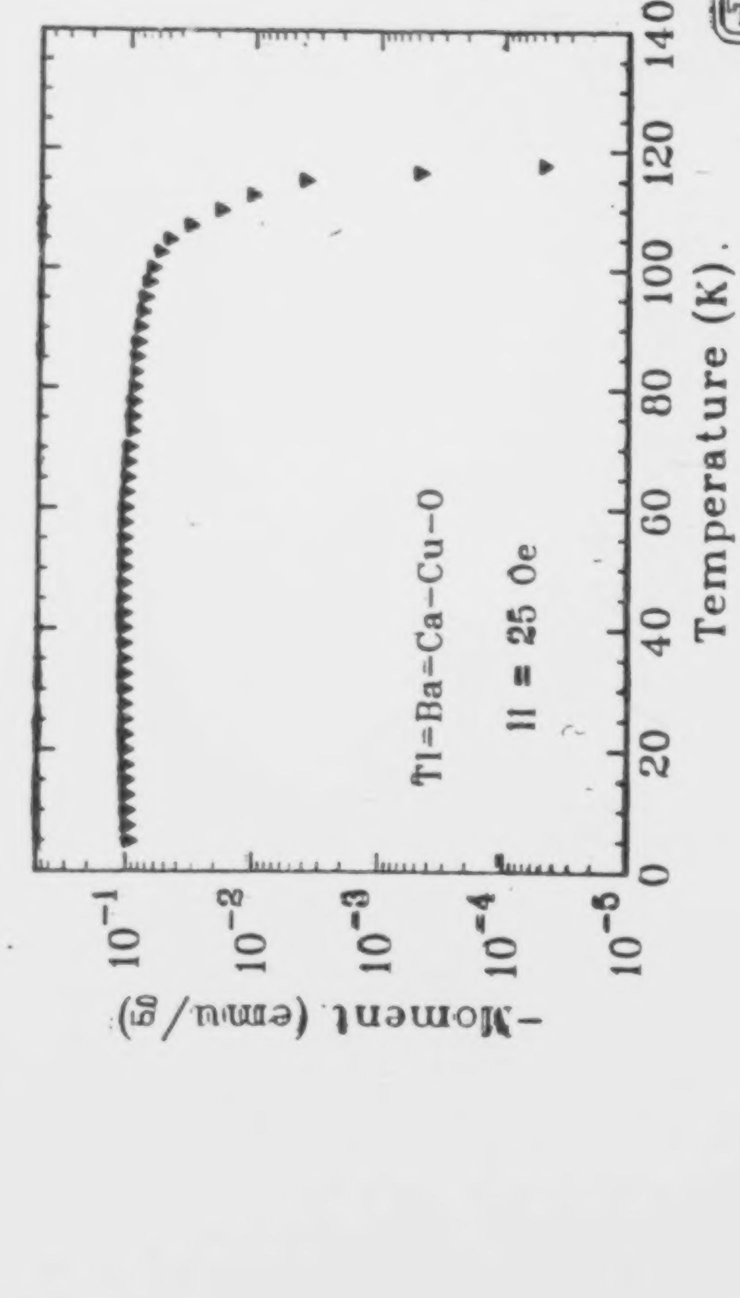
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40
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Temperature (K)

Attachment 2

The Combustion Research Facility
Sandia National Laboratories

Introduction. More than a decade ago, in response to a national energy crisis, Sandia proposed to the U. S. Department of Energy a new, ambitious program in combustion research. Our strategy was to apply the rapidly increasing capabilities in lasers and computers to combustion science and technology. Shortly thereafter, the Combustion Research Facility (CRF) was established at Sandia's Livermore location. Designated a "User Facility", the charter of the Facility was to develop and maintain special-purpose resources to support a nationwide initiative — involving U. S. universities, industry, and national laboratories — to improve our understanding and control of combustion.

Today, the Combustion Research Facility occupies a unique niche among the Department of Energy "User Facilities." Resources are diverse, and include specialized lasers, computers, and more than two dozen laboratories optimized for the study of combustion-related processes. These resources are applied to a broad range of related research activities that typically involve individual or small collaborative groups of researchers.

The core of Sandia's Combustion Program is funded by the Division of Chemical Sciences within the Office of Basic Energy Sciences (see Figure 1). Starting at a level of $250K in 1976, annual funding for our core program has grown to nearly $6M, covering operations of the Combustion Research Facility and a diagnostics development effort, support for our Visiting Scientist Program, and funding for an in-house research program.

To promote the use of the CRF as a User facility, we maintain an aggressive Visiting Scientist Program. We actively seek representatives of industry, academia and national laboratories to come to the CRF and take advantage of its resources (see Figure 2). Some visitors stay for extended periods (a few weeks to a year or more) to conduct independent or collaborative research using unique CRF capabilities. Over the past few years, the number of long-term visitors has increased steadily (see Figure 3), to be compared with the number of resident professionals (approximately 40).

University Interactions. The CRF actively supports U.S. universities through extended visits by graduate students and faculty under the auspices of our Visiting Scientist Program. By making CRF resources and staff available for the stewardship of on-site graduate students, we contribute effectively to the training of the next generation of U. S. scientists. CRF programs actively encourage extended faculty participation through BES-supported summer visits, sabbatical visits, and consulting arrangements. In 1987, the CRF hosted 422 university visitors; 48 of these visitors stayed for extended periods. Furthermore, the CRF participates actively in the nationally mandated Historically Black Colleges and Universities (HBCU) program as well as in the Association of Western Universities (AWU).

In an effort to extend our interactions with the university community, the CRF has developed a program to support postdoctoral research in combustion science and technology. We presently have fifteen postdoctoral scientists working with CRF staff. Through our stringent selection criteria and the close coupling of postdoctoral scientists with existing CRF activities, we expect this program to contribute significantly to our training mission.

Industry Interactions. Since its inception the Combustion Research Facility has developed and maintained strong interactions with U. S. industry. The emphasis of these interactions is on providing the technology base for clean, efficient energy utilization, and on enhancing the overall competitiveness of U. S. industry in the world marketplace.

Similar to CRF-university interactions, the CRF Visiting Scientist Program serves as a focus for CRF-industry interactions. Since 1981, the CRF has hosted more than 1600 industrial visitors, many of whom (188) have been in residence for periods of a few weeks up to a year or more. Industrial scientists and engineers come frequently with their own equipment and exploit the CRF's unique diagnostic and computational resources to answer questions of critical importance to long-term development of competitive marketplace products.

Cooperative "working groups", instituted at the CRF over a decade ago, foster strong industrial interactions by bringing together representatives from industry, universities, and national laboratories to study combustion technology issues related to engine knock, diesel engine technology, and both direct injection stratified charge and dilute homogeneous charge engine technologies. A research-oriented working group is pursuing approaches to increase the understanding of turbulent reacting flows. Two other groups focus on pulse and spray combustion for industrial and home furnace applications. Industrial participants include General Motors, Ford, Chrysler, Cummins, Navistar, Exxon, Unocal, General Electric, Lennox, and the Gas Research Institute. In coal combustion, strong collaborative working relationships have been Consol, established with the Electric Power Research Institute and Coal Company. Major boiler manufacturers are also regularly contacted.

One measure of industrial commitment to CRF-related activities is the magnitude of "in-kind" support they provide at the CRF. An estimate of this support for the period FY1981 to FY1987, based on industrial salaries, travel, and equipment costs, is shown in Figure 3. For comparison, data are also plotted reflecting the BES-supplied funds for operation of the CRF. Although a significant fraction of industrial support is from equipment loans, industrial "in-kind" support actually surpassed BES-supplied operations funding in FY1987. This trend is expected to continue as long as the CRF provides access to cutting-edge combustion science.

Technology Transfer. The Combustion Research Facility has had a significant impact on U. S. industry in "technology transfer" by fostering the development of new companies, new products, new technologies, and new programs.

Technor — formed by inventor and former CRF scientist Dr. Robert A. Perry — is commercializing the RAPRENOx (rapid reduction of nitrogen oxides) process to diesel engine and other industrially significant systems. Dr. Perry left the CRF in May 1987 after obtaining patent rights and a DOE SBIR grant to pursue the process. Although commercialization is expected to take several years, RAPRENOx holds great promise for controlling nitrogen oxide emissions.

Much of the combustion-related technology base is contained in sophisticated computer codes which combine state-of-the-art numerical methods with up-to-date data bases. For example, the CHEMKIN code, used to analyze chemical kinetics, has been supplied to over two hundred researchers in both industry and academia. A sophisticated computer code to analyze coherent anti-Stokes Raman spectra, developed in the CRF diagnostics effort, has also been supplied (on request) to industrial users. The development by CRF scientists of a chemical mechanism for the removal of NOx by ammonia injection was also embodied in a computer code, which was used subsequently by industrial workers to develop a computer-based engineering tool that reportedly has reduced design and installation costs of practical hardware.

BES-supported research at the CRF led directly to the development of mode-locked injection-seeding lasers, that were recently commercialized by Lightwave Electronics, Inc. Our recent design of a permanent-magnet Faraday-isolator has stimulated the development of a new company, Electro-Optics Technologies. Other examples include flashlamp-pumped dye laser oscillators, and pulsed laser wavemeters.

International Perspective. These CRF activities foster U. S. competitiveness in the international arena of combustion research and technology. Programs at the Combustion Research Facility entirely constitute the U. S. contribution to the International Energy Agency's (IEA) Energy Conservation in Combustion Agreement. The CRF is a significant participant in the International Combustion Symposium (with more papers accepted on a competitive basis than most countries), and a host of other international scientific exchanges. The CRF has established significant collaborations with foreign industries, such as Toshiba, Institute Francais Petrole, and Hitachi. These interactions are structured to assure enhancement of the U. S. competitive posture by insisting on *quid pro quo* exchanges of meaningful technology. Our objective is to continue to serve as a conduit through which international technology flows into U. S. industry.

Because combustion plays such a dominant role in international energy production, many foreign countries are developing research programs that parallel the structure of the Combustion Research Facility. One example is Germany's TECFLAM, a consortium which involves German industry and universities, with active government support. Patterned specifically after the CRF, this effort is already twice the size of our program. In France, universities and industry are strongly coupled in engine research programs centered at Rouen, Lille, Peugeot, and ONERA. Sweden, Denmark and Holland are embarking on ambitious programs, also evolving from a close collaboration with representatives of the CRF, to apply modern combustion methods to energy production, with a long-term goal of reducing dependence on nuclear energy. Strong efforts are also underway in Japan, England, Italy, Norway, and Canada to apply modern diagnostic and computer modeling techniques to combustion.

Based on current information, we estimate that in excess of $60M is being spent annually on combustion research outside of the United States. The Common Market alone has recently budgeted $10M for a new cooperative engine research program through the Commission of the European Communities. The extent to which this coordinated activity is due to stimuli provided by programs at the CRF is difficult to assess, but is by no means negligible.

The Future. The combustion of fossil fuels will continue to supply most of our energy needs into the foreseeable future. To assure the long-term energy security of the U. S., we have developed a proposal — CRF Phase II — to increase laboratory space, add next-generation laser diagnostic capabilities, and greatly improve supercomputer access within the CRF. Our proposal was developed early in the 1980s, first submitted to DOE in FY1984 and subjected to critical peer review in 1986. Funding was first received (through Congressional initiative) in FY1987. Subsequent funding was provided in FY1988; completion is anticipated in FY1992.

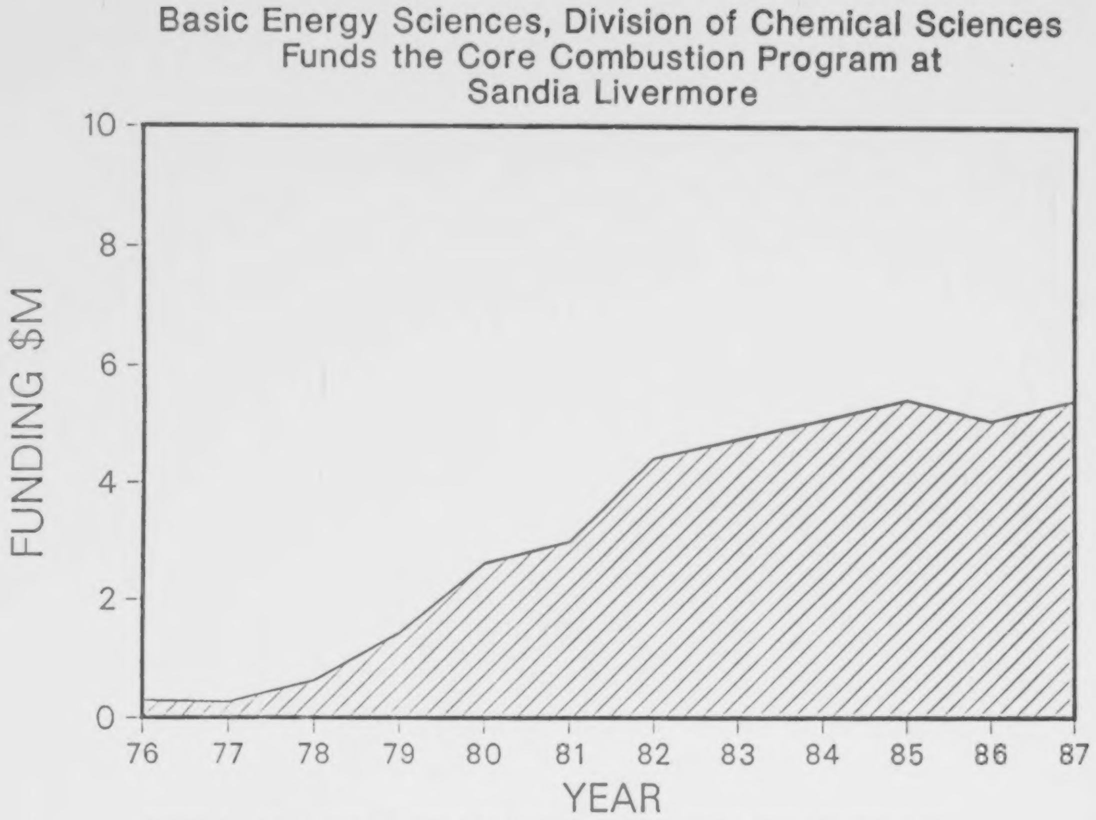

Figure 1. Combustion Research Facility funding received from the Office of Basic Energy Sciences, Division of Chemical Sciences for the Period FY1976 to FY1987. Data include support of in-house research, in addition to facility operations.

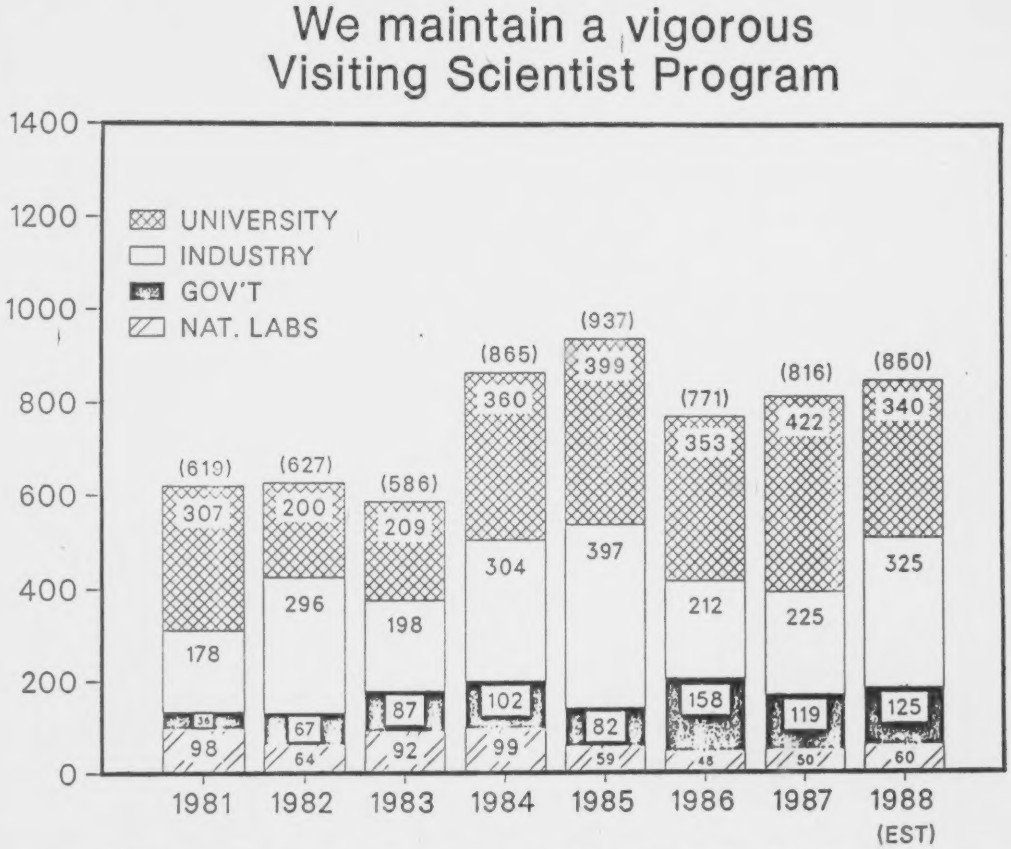

Figure 2. Summary of visitor statistics at the Combustion Research Facility for the period 1981 to 1987.

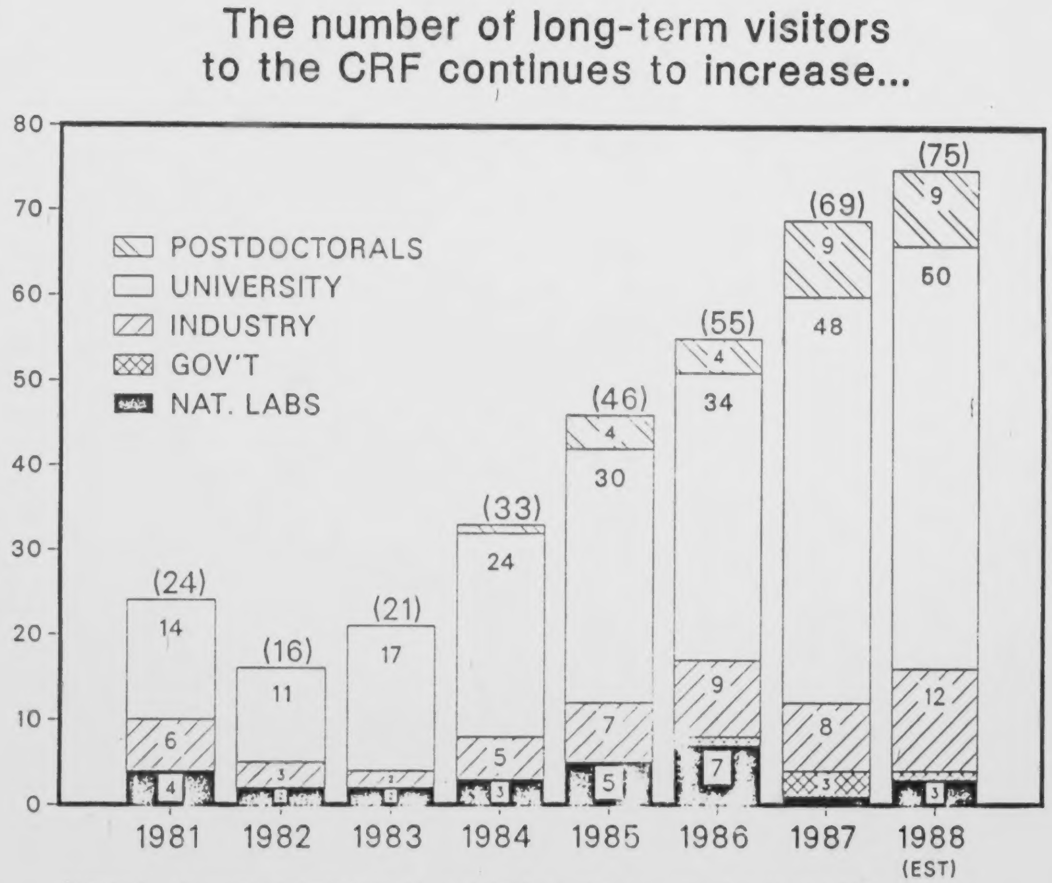

Figure 3. Summary of long-term (i.e. length of stay greater than two weeks) at the Combustion Research Facility for the period 1981 to 1987.

Attachment 3

A GEOSCIENCE RESEARCH PARK

A Fundamental Understanding is Needed

Effective use of the nation's energy resources is an essential facet of our economic security and contributes significantly to our stature in the international arena. Resource use ranges from discovery through utilization to disposal of waste byproducts. In recent years we have experienced a decline in the availability of high-grade energy resources, reflecting the fact that the U.S. has become a mature producer. There is little doubt that we will be using lower grade, and different, resources in the future. Also in recent years we have seen a growing awareness, and concern, for environmental quality. In particular, there are national and local concerns about the impact of disposing of wastes generated through energy-related activities on the safety of our groundwater supplies. An issue of growing local concern is the contamination of our groundwater with petroleum products.

The Geosciences, Geology, Geophysics, Geochemistry, and Geomechanics have been of vital importance in the development of the nation's energy resource base. In the past the emphasis has been on the origin, distribution, and evolution of the resource with only minor concern regarding applied aspects of usage. The demands of the future will inevitably emphasize the need to use lower grade resources and to reduce adverse environmental consequences of energy resource use. A key factor in both cases is the establishment of a new link between the often more basic research in the Geosciences and its application, as in Geoengineering. In general this linkage has not been well made in the nation's academic institutions, being more suited to an environment with a specific mission orientation. In a broader sense, there is a vital need to bring together investigators from a wide range of disciplines in science and engineering to deal with the overall problems of energy resource use.

A Geoscience Research Laboratory Is Proposed

To create this vital new linkage between Geoscience, Geoengineering, and the related disciplines, establishment of a Geoscience Research Park at Sandia National Laboratories is recommended. The initial phase of this facility would involve using one-half of a 40A site to construct a Geoscience Research Laboratory of 65,000 sq. ft., and a large-scale outdoor Geoscience Simulation Facility. The construction and equipment cost would be approximately $19,000,000 for the first phase of this park. Construction and operation of the overall facility would be under the direction of DOE's Office of Energy Research, consistent with the key role of OER in developing the base for new energy technologies for the nation. The facility would be operated as a National Users Facility, with the guidance and support of a Users Group, composed of eminent contributors in the field. The Park would be a facility for visiting scientists and engineers, an ever changing mix of personnel from other federal laboratories, state institutions, universities, and industrial organizations, as well as those from Sandia.

A Geoscience Research Laboratory will be a unique resource for the geoscience community to:

- Allow mechanical and geophysical testing of large samples
- Focus development and testing of advanced in situ instrumentation
- Provide field deployment of instrumentation hardware for research or for use in national emergencies
- Facilitate teamwork between scientists and engineers
- Provide a logical location for the Geoscience Research Drilling Office
- Transfer new technologies to industry, universities, and government

Sandia is the proper location

Sandia National Laboratories, Albuquerque, is the proper location for a Geoscience Research Laboratory because the facility is needed to meet current and future commitments in geoscience -- particularly the CSDP and its Drilling Research Office. Also, Sandia is an active, key participant in numerous geoscience, fossil energy, geothermal energy, waste disposal and other programs which provide a collective benefit. Sandia is especially accomplished in the areas of advanced instrumentation development, geophysical testing, and field testing.

AREAS OF CURRENT SANDIA NATIONAL LABORATORIES' CONTRIBUTION AND EXPERTISE

- FUNDAMENTAL RESEARCH
  - GEOMECHANICS, GEOCHEMISTRY & GEOPHYSICS
  - CONTINENTAL SCIENTIFIC DRILLING PROGRAM
    - SITE SPECIFIC RESEARCH
    - INSTRUMENTATION DEVELOPMENT
    - DOE GEOSCIENCE RESEARCH DRILLING OFFICE

- GEOTHERMAL ENERGY
  - DRILLING AND COMPLETIONS LEAD LAB
  - HIGH TEMPERATURE INSTRUMENTATION
  - MAGMA ENERGY LEAD LAB

- FOSSIL ENERGY AND GAS
  - ENHANCED OIL RECOVERY
  - IN SITU PROCESSING OF COAL AND OIL SHALE
  - SEA FLOOR STABILITY
  - SUBSIDENCE

- NUCLEAR WASTE
  - WIPP GEOTECHNOLOGY AND IN SITU R&D
  - SUBSEABED DISPOSAL LEAD LAB
  - NEVADA NUCLEAR WASTE STORAGE INVESTIGATIONS

- RESPONSE TO NATIONAL CONCERNS/EMERGENCIES
  - ERUPTIONS, EARTHQUAKES
  - DAM STABILITIES
  - COAL MINE FIRES
  - ENVIRONMENTAL HAZARDS

- IN-COUNTRY SEISMIC VERIFICATION PROGRAM

- NUCLEAR WEAPONS TESTING
  - GROUND MOTION
  - CONTAINMENT

- FIELD TEST CAPABILITIES
  - LARGE SCALE MOBILIZATION
  - EXTENSIVE PORTABLE INSTRUMENTATION
  - IN SITU TESTING

THH6000.16

Mr. VALENTINE. Thank you, Dr. Hartley. Dr. Winick.

STATEMENT OF DR. HERMAN WINICK, ACTING DIRECTOR, STANFORD SYNCHROTRON RADIATION LABORATORY, STANFORD, CA

Dr. WINICK. Thank you, Mr. Chairman and members of the Committee. I am pleased to say that with me here today is Dr. Joe Wong of the Lawrence Livermore National Laboratory, who is Chairman of the SSRL Users Organization. I call your attention to a letter from Dr. Wong which is in the package just after the first colored divider, which expresses the views and concerns of the users of SSRL. I will be covering some of those points here, of course.

I would also like to mention that the Director of the facility, Professor Bienenstock who would be here today normally, is on sabbatical at the Grenoble facility, the European Synchrotron Radiation facility which you have heard mentioned.

I appreciate the opportunity to discuss SSRL and its major activities; its user community, its relationships to other DOE-funded laboratories, and the impact of the President's proposed fiscal year 1989 Basic Energy Sciences budget on SSRL operations and research.

Our remarks will give you some background on SSRL, its utilization of the SPEAR and PEP storage rings at the Stanford Linear Accelerator Center [SLAC] and the impact of the Laboratory on basic and applied research in the United States.

The major points of my testimony are the following: One, the core support funding recommended for SSRL in the President's budget for 1989 will provide the 650 scientists now involved with the program on the SPEAR ring with the lowest level of operations and staff support since the start of dedicated operation in fiscal year 1980.

With the beam time already in extreme overdemand, this reduction will necessarily cause drastic delays in important scientific and technological research projects. Some of these projects are of major importance to U.S. high-technology industries as evidenced by the large financial investments these companies have made in programs at SSRL.

Another program is important for the development of a major potential improvement in the diagnosis and treatment of heart disease. You heard Dr. Schriesheim mention the angiography work which SSRL has actually pioneered in. Other programs are very important to U.S. defense laboratories which have also made major investments in facilities at SSRL.

Two, another major negative consequence of the budget shortfall is the loss of the opportunity to exploit the unique capability of the existing large PEP storage ring, which is presently the most advanced x-ray synchrotron radiation source in the world and which has in the last few months been shown to have the capability to achieve a quantum leap in scientific performance.

PEP offers the Nation the opportunity to maintain a half-decade lead in synchrotron radiation research, which has proved to be so important to academic, government and industrial programs. If this opportunity is not exploited, leadership in this field will shift from the United States to Japan or Europe.

Three, it is proposed therefore, that funds be added—that is new funds—to the DOE budget in Basic Energy Sciences to increase the SSRL core support from $11.25 million to $14 million. I refer you to page 10 of this testimony package for details of this proposal.

This increase will permit the start of dedicated operation of PEP along with about a doubling of the running time in SPEAR with immense benefit to academic, industrial and Government scientists in this country and a corresponding major increase in return on the large capital investment in existing facilities. It includes only a cost-of-living increase in general operating expenses.

During SSRL's 14 years of operation, the Laboratory has earned an international reputation for its accomplishments in research and instrumentation development. As the first high energy storage ring source of synchrotron radiation, the work done at SSRL has spawned the creation of other U.S. facilities now in full operation at Brookhaven National Laboratory and the University of Wisconsin, and the successful recent completion of the world's most advanced x-ray beam lines at SSRL.

In addition, it has led to the national commitment to construct very powerful third-generation sources at the Lawrence Berkeley Laboratory and at Argonne, about which you heard a bit earlier. I want to point out that we at SSRL support the decision to construct these third-generation facilities because we are well aware that greater capacity on advanced synchrotron radiation facilities is necessary for the long-term, scientific, technological and economic health of the country.

They will be major additions when they become operational in 1995, or soon thereafter. Nevertheless, for decades to come the Nation will depend on the effective functioning of, and smaller-scale additions to, the five excellent facilities now in operation.

This dependency will be greatest until the new facilities become operational. The present facilities must therefore, have adequate operations budget if the many important research programs performed at them are to be maintained. Unfortunately, however, the level of support for the operation of SSRL in the President's budget falls far short of that required to meet the demonstrated need.

Underutilization of present capability is wasteful, considering the large capital investment in these facilities. It compromises the scientific and technological competitiveness of this country, vis-á-vis Europe and Japan. It is also inconsistent with the planned construction of new facilities since completing these facilities and bringing them on line can be done more effectively and efficiently by utilizing existing facilities to help solve some of the difficult technical problems involved.

In this regard, operation of the storage-ring PEP by SSRL is particularly important. It is the only storage ring in the world with beam lines which can function at the brightness levels of the proposed next-generation x-ray storage rings. Failure to take advantage of opportunities to run PEP in a mode dedicated to synchrotron radiation will delay for years the very experiments for which these new rings are being constructed.

Valuable scientific and technological opportunities will be lost. In addition, effective utilization of the new rings will be set back.

The Stanford Synchrotron Radiation Laboratory is a national facility funded by the Department of Energy for the utilization of synchrotron radiation in biology, chemical engineering, chemistry, electrical engineering, geology, material science, medicine, physics and other disciplines.

As you have heard, synchrotron radiation provides x-ray beams with intensities which are 10,000 to a million times greater than all other steady-state sources. Such increases in intensities necessarily lead to revolutions in our scientific and technological capabilities.

Other speakers have described some of these applications, and in the interest of brevity, I will skip the next part which I refer you to in the submitted written testimony. These topics are also covered in some detail in the letters from users that are appended to the back of the package. As you can see, just briefly ranging through them and as you have heard, they range from work on understanding high-temperature superconductivity to diagnosis of blockages of coronary arteries, to the carrying out of x-ray microscopy, x-ray microtomography, x-ray lithography.

Let me now describe SSRL and the accomplishments of this facility over the past 14 years. Although they are administratively distinct, SSRL is situated on the site of the Stanford Linear Accelerator Center, SLAC, and uses the two SLAC electron-storage rings which were originally constructed for high energy physics research. These are the 3–4 GeV SPEAR ring and the 5–16 GeV PEP ring.

It would probably require about $200 million to duplicate these rings today. Large currents of electrons circulating in these rings emit copious amounts of synchrotron radiation in the form of ultraviolet light and x-rays as the electrons are curved during their passage through the storage ring bending magnets.

Even more radiation is emitted by passing the electrons through special magnets called wigglers and undulators which can be placed between the bending magnets. This radiation is transported to the SSRL experimental stations and used for research purposes.

SSRL has 24 experimental stations available to the user community. Of these, 22 are on the SPEAR ring and two are on the PEP ring. Eleven of these stations receive radiation from very powerful wiggler and undulator magnets which offer the highest flux and brightness in the world.

This is a larger number of such stations than on any other existing facility and, in fact, larger than the sum total of all other U.S. facilities.

The SSRL user community includes about 650 scientists involved in 158 active research proposals. SSRL users come from 114 institutions, 30 States, 10 foreign countries, as shown on the attached listing. Of these institutions, 49 are universities, 27 corporations, 13 Government laboratories, and 25 are foreign.

SSRL provides an atmosphere in which collaborations between scientists from industry, university and Government labs develop quite easily to the mutual benefit of the partners. In fact, about one-third of SSRL proposals are for collaborations between industry and university scientists.

Over 2,000 publications have resulted from research at SSRL over the past 14 years; 160 of these were published last year. Graduate students from 19 universities have written 126 theses based on work at SSRL. These statistics are summarized in the tables at the end of this narrative.

Finally, in terms of background, SSRL was funded this year for the construction of a separate 3-GeV injector for the SPEAR ring. This injector, by eliminating the need to fill the SPEAR ring with the SLAC linac, will not only increase the number of shifts available on the ring but will eliminate interference with the use of the linac in the operation of the Stanford Linear Collider.

Perhaps the most significant single development at SSRL during the past year was the demonstration of the capability of the PEP storage ring as a low-emittence, high-brightness synchrotron radiation source. During a 12-day period made available to SSRL by SLAC last December, approximately 20 scientists from SSRL, SLAC and LBL and both the Argonne and Brookhaven National Laboratories operated the PEP storage ring at 7.1 GeV in a low-emittence mode to produce laser like beams of x-rays about as bright as beams planned for the third-generation storage rings at Berkeley, Argonne and in other countries.

However, as I have stated before, these new rings will not be operational as you have heard from other speakers too, until about the middle of the next decade. Until these new rings are available, PEP offers unique opportunities to synchrotron radiation research, machine development that will, in fact, be extremely important in the design of these new facilities.

The importance of PEP operation to the planning and design of the Advanced Photon Source at Argonne National Laboratory is described in two attached letters; first from Dr. Alan Schriesheim, who you heard from earlier, Director of Argonne; the other from Dr. David Moncton, Interim Associate Laboratory Director for the Advanced Photon Source.

The potential of PEP as a synchrotron radiation source goes beyond the level demonstrated in the December run. Its high-energy, large-circumference, and long straight sections give it a flexibility that will permit its development to even higher performance levels beyond that which could be provided by the third-generation rings now in construction.

Thus, PEP could be the prototype of an even more powerful ring for the 21st Century in maintaining this country's leadership in this field. I regret to say, however, that the President's proposed budget for Basic Energy Sciences is not likely to allow for dedicated operation of this unique ring in fiscal year 1989.

Funding for the core support of SSRL is provided by the Department of Energy's Office of Basic Energy Sciences in the form of operation expenses and capital equipment. Basic Energy Sciences also funds constructions projects.

In the table on page 10 of my submission we show the fiscal year 1987 and 1988 funding, $10.777 million and $11.21 million respectively for SSRL core support. The next column shows the President's fiscal year 1989 budget for $11.25 million. Finally, the right hand column of the table shows our present proposal for $14 million for this critical portion of SSRL funding.

In fiscal year 1987, SSRL operated SPEAR for use as a dedicated storage ring for 323 scheduled shifts of 8 hours each. PEP did not operate at all in fiscal year 1987. During the current year, we had hoped to operate SPEAR in the dedicated mode for a total of approximately 300 scheduled shifts, about the same as in 1987, but significantly less than the 400 shifts available from SLAC.

It now appears that our budget this year will not be adequate for this level of SPEAR operation. During fiscal year 1988, PEP was operated for synchrotron radiation purposes for 36 shifts for the accelerator physics studies and the exploratory research discussed above. SLAC plans to recommence colliding operation of PEP later in this fiscal year and SSRL will operate parasitically at that time.

I hope that this information has demonstrated the importance to the synchrotron radiation community that SPEAR be operated at its fullest. If we are to respond to this demand within the President's proposed fiscal year 1989 budget—that is to include the full utilization of SPEAR—we do not have sufficient funds to operate the PEP storage ring and must also reduce our other research and operations costs by 7.5 percent in spite of inflation.

This is inconsistent with properly staffing facilities, supporting users, maintaining the beam lines and performing staff research. In other words, that possibility is just not feasible. Equally important in the long run is the lost opportunity to run PEP as a high-brightness source using the two magnificent beam lines recently completed.

I believe it is vital to the American scientific and technological community for us to strive for dedicated operation of SPEAR for the full 400 shifts that are available and to begin dedicated operation of PEP for synchrotron radiation research to maintain this country's leadership in this field.

Recently SLAC prepared new estimates for the available dedicated operating time and costs for both the SPEAR and the PEP rings in fiscal year 1989. These estimates were for $3.6 million for 400 SPEAR shifts and $1.6 million for 180 PEP shifts. Using these figures, I propose the restoration of PEP operating funds, $1.6 million, a cost of living increase over the fiscal year 1988 funding of general operating expenses, and an additional $0.26 million over the President's budget for capital equipment funding.

This proposal is shown on the right hand column of page 10. $2.75 million increase over the President's budget recommendation, although far short of our original request, will have very significant positive consequences for the SSRL and the national synchrotron radiation programs.

Thank you for your attention.

[The prepared statement of Dr. Winick follows:]

Testimony Before the Hearings of the Subcommittee on Energy Research and Development

House Committee on Science, Space and Technology

March 23, 1988

H. Winick, Acting Director
Stanford Synchrotron Radiation Laboratory

Madam Chairman and Members of the Committee:

I appreciate the opportunity to discuss the Stanford Synchrotron Radiation Laboratory (SSRL), its major activities, its user community, its relationships to other DOE-funded laboratories and the impact of the President's proposed FY 1989 Basic Energy Sciences budget on SSRL operations and research. My remarks will give you background on SSRL, its utilization of the SPEAR and PEP storage rings at the Stanford Linear Accelerator Center (SLAC) and the impact of the laboratory on basic and applied research in the United States.

The major points of my testimony are the following:

1) The "core support" funding recommended for SSRL in the President's budget for FY 1989 will provide the 650 scientists now involved with the program on the SPEAR ring with the lowest level of operations and staff support since the start of dedicated operation in FY 1980.

   At the level of funding now recommended I estimate that we could operate SPEAR for only about 200 of the 400 available 8 hour shifts. With beam time already in extreme overdemand, this reduction will necessarily cause drastic delays in important scientific and technolgical research projects. Some of these projects are of major importance to U.S. high technology (e.g., semiconductor, computing and petroleum refining) industries, as evidenced by the large financial investments these companies have made in programs at SSRL. Another is important for the development of major potential improvements in the diagnosis and treatment of heart disease.

2) Another major negative consequence of the budget shortfall is the loss of the opportunity to exploit the unique capability of the existing, large (1.4 miles in circumference) PEP storage ring, which is presently the most advanced X-ray synchrotron radiation source in the world and which has in the last few months been shown to have the capability to

achieve a quantum leap in scientific performance.

PEP offers the nation the opportunity to maintain a half-decade lead in synchrotron radiation research, which has proved to be so important to academic, government and industrial programs. If this opportunity is not exploited, leadership in this field will shift from the U.S. to Japan or Europe.

3) It is proposed,therefore, that funds be added to the DOE budget in Basic Energy Sciences to increase SSRL core support from $11.25M to $14.0M.

This increase will permit the start of dedicated operation of PEP along with about a doubling of the running time on SPEAR with immense benefit to academic, industrial and government scientists in this country and a corresponding major increase in return on the large capital investment in existing facilities. It includes only a cost-of-living increase in general operating expenses.

During SSRL's 14 years of operation the laboratory has earned an international reputation for its accomplishments in research and instrumentation development. As the first high energy storage ring source of synchrotron radiation, work done at SSRL has spawned the creation of other U.S. facilities now in full operation at Brookhaven National Laboratory (BNL) and the University of Wisconsin and the successful recent completion of the world's most advanced X-ray beam lines at SSRL. In addition it has led to the national commitment to construct very powerful, third generation sources at the Lawrence Berkeley Laboratory (LBL) and the Argonne National Laboratory (ANL).

I should point out that we at SSRL support the decision to construct these third generation facilities because we are well aware that greater capacity on advanced synchrotron radiation facilities is necessary for the long-term scientific, technological and economic health of the country. This is, of course, why similar projects are underway in other parts of the world, particularly Europe and Japan. This large-scale international commitment of resources (e.g., about $100M for the Advanced Light Source [ALS] at LBL and about $400M for the Advanced Photon Source [APS] at ANL and a similar amount for a comparable facility in Grenoble, France) to the development of synchrotron radiation facilities is ample evidence of the importance of such facilities to scientific and technological advances. They will be major additions when they become operational in 1995 or soon thereafter.

Nevertheless, for decades to come the nation will depend on the effective functioning of, and smaller-scale additions to, the five excellent facilities now in operation. This dependency will be greatest until the new facilities become operational. The present facilities must therefore have adequate operations budgets if the many important research programs performed at them are to be maintained. Unfortunately, however, the level of support for the operation of SSRL in the President's budget falls far short of that required to meet the demonstrated need.

The underutilization of present capability is wasteful considering the large capital investment in these facilities. It compromises the scientific and technological competitiveness of this country vis-a-vis Europe and Japan. It is also inconsistent with the planned construction of new facilities, since completing these facilities and bringing them on-line can be done more effectively and efficiently by utilizing existing facilities to help solve some of the difficult technical problems involved.

In this regard, operation of the storage ring PEP by SSRL is particularly important. It is the only storage ring in the world with beam lines which can function at the brightness levels of the proposed next-generation X-ray storage rings. Failure to take advantage of opportunities to run PEP in a mode dedicated to synchrotron radiation will delay for years the very experiments for which these new rings are being constructed. Valuable scientific and technological opportunities will be lost. In addition, effective utilization of the new rings will be set back. That is, the solutions to difficult technological problems which must be obtained before these new facilities can function at their full effectiveness are likely to be delayed until the rings are in operation in the mid-90's. PEP could be used to study and resolve these problems. Potential solutions could be tested on it.

A number of major committees have spoken to the point of adequate funding for the operation of existing facilities. One example is the "Planning Study for Advanced National Synchrotron Radiation Facilities" that was sponsored by the Office of Basic Energy Sciences. This study, prepared under the chairmanship of Drs. Peter Eisenberger and Michael Knotek, states in its first recommendation:

> "To optimize utilization of existing facilities, we recommend providing operations funding, so that such facilities can provide a maximum of beam time in a "user friendly" mode, and continued research funding, so that it will be possible to take full advantage of the facilities."

It is to this point, particularly as it relates to SSRL, that I wish to draw your attention.

A. BACKGROUND

The Stanford Synchrotron Radiation Laboratory (SSRL) is a national facility, funded by the Department of Energy, for the utilization of synchrotron radiation in biology, chemical engineering, chemistry, electrical engineering, geology, materials science, medicine, physics and other disciplines.

Synchrotron radiation provides X-ray beams with intensities which are ten thousand to a million times greater than all other steady-state sources. Such increases in intensities necessarily lead to revolutions in our scientific and technological capabilities. Let me, therefore, describe some of the types of questions which can now be answered using intense synchrotron radiation.

1. What are the atomic arrangements in the new high-temperature superconductors? It appears vital to determine these arrangements in order to understand the nature of this exciting and important new phenomenon.

2. Can we avoid catheterization in the diagnosis of blockages of heart arteries? The catheterization process which is presently employed to locate coronary arterial blockages is relatively dangerous, with a morbidity rate of approximately one in two hundred and a mortality rate of approximately one in a thousand. As a result the procedure cannot be used to perform routine follow-ups of patients who have been shown to be at risk or who have received surgery. At SSRL, in collaboration with scientists from Stanford University, Lawrence Berkeley Laboratory and Brookhaven National Laboratory, techniques are being developed for obtaining high quality radiograms without using the arterial catheterization procedure. Research has been done on a small number of human patients at SSRL and valuable, and in two cases, clinical, information was obtained.

3. How are atoms arranged in proteins? How do those atoms rearrange as the proteins go through their biological functions?

4. What are the atomic surroundings of very dilute constituents of solids and liquids? Frequently small quantities of "impurity" atoms are added to glasses, metals and semiconductors to achieve desirable physical or chemical properties for scientific or technological utilization. Synchrotron radiation makes it possible to determine how those impurity atoms are bonded in these materials. It makes possible detailed understanding of the relationship between that bonding and the associated properties.

5. What are the arrangements of atoms on the surfaces of materials? What is the nature of the bonding of these atoms to the surface? Such studies are important, for example, to understand how metals corrode or how sulphur poisons a catalyst. In years to come we will obtain more detailed understandings of how materials wear with these techniques.

6. **What is the nature of the interface between a metal and a semiconductor?** That interface play a critical role in today's integrated circuits. As such circuits are made on a finer and finer scale, it becomes increasingly important to understand that interface at an atomic level.

7. **What are the concentrations of extremely dilute species in materials?** For example, it was once believed that super heavy elements were present in an ore sample. It has been said that our weapons program would have been strongly influenced had these elements been present. Extremely sensitive analysis of these materials was performed at SSRL to show that the super heavy elements were not, in fact, present at the concentrations stated or even at considerably lower concentrations.

8. **How effectively can we make an X-ray microscope to obtain information which is not provided by optical or electron microscopes?**

9. **How effectively can we perform X-ray lithography to produce very large scale integrated circuits?** As we seek to make electronic circuits on silicon chips increasingly dense, the limit of detail which can be achieved with lithography through visible or ultraviolet light is rapidly being approached. To go further, X-rays and/or particle beams will be used to perform the lithography. Synchrotron radiation is a primary candidate for this purpose. It is therefore vital to our computer industry that the nation's synchrotron radiation laboratories provide facilities for the development of advanced techniques.

Many, if not all, of these subjects are mentioned in the attached letters from members of the SSRL user community.

Let me now describe SSRL and the accomplishments at this facility over the past 14 years. Although they are administratively distinct, SSRL is situated on the site of the Stanford Linear Accelerator Center (SLAC) and uses the two SLAC electron storage rings which were originally constructed for high energy physics research. These are the 3-4 GeV (billion electron volts) SPEAR ring and the 5-16 GeV PEP ring. It would probably require about $200M to duplicate these rings today.

Large currents of electrons circulating in these rings emit copious amounts of synchrotron radiation in the form of ultraviolet light and X-rays as the electrons are curved during their passage through the storage ring bending magnets. Even more radiation is emitted by passing the electrons through special magnets called wigglers and undulators which can be placed between the bending magnets. This radiation is transported to the SSRL experimental stations and used for research purposes.

SSRL has 24 experimental stations available to the user community. Of these, 22 are on the SPEAR ring and two are on the PEP ring. Eleven of these stations receive radiation from very powerful wiggler and undulator magnets which offer the highest flux and brightness in the world. This is a larger number of such stations than on any other existing facility and, in fact, larger than the sum total of all other U.S. facilities. The pioneering work done at SSRL, much of which was carried out in collaboration with the Lawrence Berkeley Laboratory, in the development and utilization of wiggler and undulator sources, has been a major impetus for the planning for the next generation of rings which will be based primarily on the use of such sources.

The SSRL user community includes about 650 scientists involved in 158 active research projects. This number represents a large increase in the user population over only the last two years and was brought about by the successful commissioning of new beam lines and experimental stations and by the influx of new communities of industrial scientists working in the areas of biotechnology and semiconductor technology, the latter using the new SSRL X-ray lithography station.

SSRL users come from 114 institutions from 30 states and 10 foreign countries as shown on the attached listing. Of these institutions, 49 are universities, 27 are corporations, 13 are government laboratories and 25 are foreign. SSRL provides an atmosphere in which collaborations between scientists from industry, universities and government laboratories develop quite easily, to the mutual benefit of the partners.

Over 2,000 publications have resulted from research at SSRL over the last 14 years; 160 of these were published last year. Graduate students from 19 universities have written 126 theses based on work done at SSRL. These statistics are summarized in tables at the end of this narrative.

Finally, in terms of background, SSRL was funded this year (FY 1988) for the construction of a separate 3 GeV injector for the SPEAR ring. This injector, by eliminating the need to fill the SPEAR ring with the SLAC linac, will not only increase the number of shifts available on the ring but will eliminate interference with the use of the linac in the operation of the Stanford Linear Collider (SLC).

B. CURRENT ACTIVITIES

I have outlined for you the breadth of experimentation performed at SSRL. This breadth can also be gleaned from the attached letters from users describing their research and their almost desperate need for additional beam time. Many of these programs require radiation with higher X-ray energy, flux or brightness. We have striven to meet these needs with the development of wiggler and undulator sources, beam line optics and monochromators.

Perhaps the most significant single development at SSRL during the past year was the demonstration of the capability of the PEP storage ring as a low emittance, high brightness synchrotron radiation source. During a 12-day period made available to SSRL by SLAC last December, approximately 20 scientists from SSRL, SLAC, LBL, and both the Argonne and Brookhaven national laboratories operated the PEP storage ring at 7.1 GeV in a "low emittance" mode to produce laser-like beams of X-rays about as bright as beams planned for third generation storage rings at Berkeley, Argonne and in other countries. However, as I stated before, these new rings will not be operational until the middle of the next decade.

Until these new rings are available, PEP offers unique opportunities for synchrotron radiation research and machine development that will, in fact, be extremely important in the design of the new facilities. (An even larger, higher energy ring in Japan will offer such opportunities when it is equipped with undulators and beam lines.) The combination of high electron energy, low emittance, long undulators and short bunches give PEP the capability to produce radiation with extremely high brightness, peak power and coherent power at X-ray energies from a few thousand electron volts to well above 100 thousand electron volts. Novel techniques using very short period undulators could extend this to several million electron volts.

The importance of PEP operation to the planning and design of the Advanced Photon Source at Argonne National Laboratory is described in two attached letters: The first, dated August 26, 1987 from Dr. Alan Schriesheim, Director of ANL; the second, dated March 18, 1988 from Dr. David Moncton, Interim Associate Laboratory Director for the Advance Photon Source. In his letter, Dr. Moncton's notes that operation of PEP with the Argonne prototype undulator magnet will be instrumental to the APS research and development program.

The potential of PEP as a synchrotron radiation source goes beyond the level demonstrated in the December, 1987 run. Its high energy, large circumference and long straight sections give it a flexibility that will permit its development to even higher performance levels, beyond that which could be provided by the third generation rings now in construction. Thus PEP could be the prototype of an even more powerful ring for the 21st century and maintain this country's leadership in this field.

I regret to say, however, that the President's proposed budget for Basic Energy Sciences is not likely to allow for dedicated operation of this unique ring in FY 1989.

C. FUNDING AND IMPACTS

Funding for the core support of SSRL is provided by the Department of Energy, Office of Basic Energy Sciences (BES) in the form of Operations Expenses (OE) and Capital Equipment (CE). (BES also funds construction projects at SSRL.)

In the table at the end of this narrative we show the FY 1987 and FY 1988 funding ($10.777M and $11.21M respectively) of SSRL core support. The next column shows the President's FY 1989 budget of $11.25M for SSRL core support. Finally, the right-hand column of the table shows our present proposal for $14M for this critical portion of SSRL funding.

In FY 1987 SSRL operated SPEAR for use as a dedicated synchrotron radiation source for 323 scheduled shifts of 8 hours each. PEP did not operate in FY 1987.

During the current year we had hoped to operate SPEAR in the dedicated mode for a total of approximately 300 scheduled shifts; about the same as FY 1987, but significantly less than the 400 shifts available from SLAC. It now appears that our budget this year will not be adequate for this level of SPEAR operation. During FY 1988 PEP was operated for synchrotron radiation purposes for 36 shifts, for ~~the~~ accelerator physics studies and the exploratory research discussed above. SLAC plans to recommence colliding beam operation of PEP later in this fiscal year and SSRL will operate parasitically at that time.

The letter from the Chairman of the SSRL Users' Organization included at the end of this narrative and the many letters from individual users appended to this report attest to this need for full operation. To provide for this we originally proposed a budget for FY 1989 that would have allowed for full 50% operation of SPEAR (410 shifts) and 270 dedicated shifts on PEP. This would have made very good use of the large capital investment made by this government in the construction and improvement of the SPEAR and PEP rings and the wiggler and undulator sources and associated beam lines and experimental stations of SSRL. It would also have significantly improved the return to industry on the several million dollar investment in facilities made at SSRL.

D. CONCLUSION AND PROPOSAL

I hope that this information has demonstrated the importance to the synchrotron radiation community that SPEAR be operated at its fullest. If we are to respond to this demand within the President's proposed FY 1989 budget (i.e., to include the full utilization of SPEAR) we do not have sufficient funds to operate the PEP storage ring and must also reduce our other research and operations costs by 7.5% ($.559M) in spite of inflation. This is inconsistent with properly supporting users, maintaining the beam lines and performing staff research. Equally important in the long run is the lost opportunity to run PEP as a high brightness source using the two magnificent beam lines recently completed.

I believe it is vital to the American scientific and technological community for us to strive for dedicated operation of SPEAR for the full 400 shifts that are available and to begin dedicated operation of PEP for synchrotron radiation research to maintain this country's leadership in this field.

Recently SLAC prepared new estimates for the available dedicated operating time and costs for both the SPEAR and PEP rings in FY 1989. These estimates were for $3.6M for 400 SPEAR shifts and $1.6M for 180 PEP shifts. Using these figures, I propose the restoration of PEP operating funds ($1.6M), a cost-of-living increase over FY 1988 funding of general operating expenses (that is, $.89M over the President's budget) and an additional $.26M over the President' budget for capital equipment funding. This proposal is shown on the right-hand column of the table at the end of this narrative.

The $2.75M increase over the President's budget recommendation, although far short of our original request, will have very significant positive consequences for the SSRL and national synchrotron radiation programs.

BASIC ENERGY SCIENCES

"CORE" FUNDING

(Dollars in Thousands)

for
OPERATIONS AND RESEARCH
at

STANFORD SYNCHROTRON RADIATION LABORATORY
Stanford University

	FY 1987	FY 1988	<---- FY 1989 ----> PRES' BUDGET	ALTERNATE PROPOSAL
A. OPERATIONS EXPENSES				
Rsch & Oprns	$ 6,901	$ 7,469	$ 6,910	$ 7,800
SPEAR Ded Time	2,951	2,736	3,600	3,600
PEP Ded Time	n/a	100	-0-	1,600
	$ 9,852	$10,305	$10,510	$13,000
B. CAPITAL EQUIPMENT				
Rsch & Oprns	$ 925	$ 905	$ 740	$ 1,000
	$10,777	$11,210	$11,250	$14,000

STANFORD SYNCHROTRON RADIATION LABORATORY

Stanford University, Stanford, CA

A NATIONAL USERS RESEARCH LABORATORY

FUNDED BY THE DOE

for utilization of synchrotron radiation for basic and applied research in medicine, the natural sciences and engineering

- 24 EXPERIMENTAL STATIONS
- 650 SCIENTISTS FROM 114 INSTITUTIONS

  49 Universities
  27 Corporations
  13 Government Laboratories
  25 Foreign Institutions
- 158 ACTIVE EXPERIMENTAL PROPOSALS FROM 136 DIFFERENT PRINCIPAL INVESTIGATORS
- 126 Ph.D. THESES FROM 19 UNIVERSITIES COMPLETED
- OVER 2000 PUBLICATIONS IN REFEREED JOURNALS
- EXPERIMENTERS FROM 30 STATES AND 10 FOREIGN COUNTRIES

MARCH 1988

Institutions with Active SSRL Research Programs - March 1988

Arizona
Arizona State University
University of Arizona

California
ARCAR Corporation
California Institute of Technology
California State University
Chevron Oil Field Research Company
Chevron Research Company
EPRI
Hewlett Packard Laboratories
IBM San Jose Research Laboratory
Intel Corporation
Lawrence Berkeley Laboratory
Lawrence Livermore National Laboratory
Naval Weapons Center
Palo Alto Veterans Hospital
Research Institute of Scripps Clinic
Sandia National Laboratory
Signetics Corporation
SRI International
Stanford University
The Aerospace Corporation
University of California (7 campuses)
Western Regional Research Center
Xerox PARC

Colorado
Colorado School of Mines
University of Colorado

Connecticut
Schlumberger-Doll Research

District of Columbia
Carnegie Institute
Naval Research Laboratory

Florida
Florida-Atlantic University
University of South Florida

Georgia
Georgia Institute of Technology
University of Georgia

Hawaii
University of Hawaii

Illinois
Argonne National Laboratory
Northwestern University
University of Chicago
University of Illinois

Indiana
Purdue University
University of Notre Dame

Maryland
National Bureau of Standards
W.R. Grace & Company

Massachusetts
Amherst College
Harvard Medical School
Harvard University
MIT

Michigan
KMS Fusion
University of Michigan

Minnesota
3M Central Research Laboratory
University of Minnesota

Mississippi
University of Mississippi

Missouri
Monsanto Company
Washington University

New Jersey
AT&T Bell Laboratories
EXXON Research & Engineering
Hoffmann-La Roche Inc
Princeton University
Stevens Institute of Technology

New Mexico
Los Alamos National Laboratory
Sandia National Laboratory
University of New Mexico

New York
Brookhaven National Laboratory
City University of New York
Columbia University
Eastman Kodak Research Laboratory
Hunter College
IBM TJ Watson Research Laboratory

North Carolina
Becton Dickinson & Company

Ohio
Case Western Reserve
Ohio State University
University of Cincinnati

Oregon
University of Oregon

Pennsylvania
Carnegie Mellon University
Macroatom, Inc.
Pennsylvania State University
University City Science Center
University of Pennsylvania

Rhode Island
Brown University

South Carolina
University of South Carolina

Tennessee
Martin Marietta
Oak Ridge National Laboratory

Texas
Texas A&M University

Utah
Brigham Young University

Washington
The Boeing Company
Pacific Northwest Laboratory
University of Washington

Wisconsin
University of Wisconsin

VIII SSRL EXPERIMENTERS AND PROPOSALS BY INSTITUTIONS

As of December 31, 1987 there were 535 experimenters from 114 institutions officially involved with active proposals at SSRL. In addition, over a 100 others (graduate students, etc.) participated in work at the laboratory in collaboration with these scientists. The 89 United States institutions included 49 Universities, 27 private corporations and 13 government laboratories.

U.S CORPORATIONS: ARACOR, AT&T BELL LABORATORIES, BECTON DICKINSON & COMPANY RESEARCH CENTER, BOEING COMPANY, CHEVRON OIL FIELD RESEARCH COMPANY, CHEVRON RESEARCH COMPANY, EASTMAN KODAK RESEARCH LABORATORY, EPRI, EXXON RESEARCH & ENGINEERING, HEWLETT PACKARD LABORATORIES, HOFFMANN-LA ROCHE INC., IBM RESEARCH LABORATORY, INTEL CORPORATION, KMS FUSION, LOCKHEED RESEARCH LABORATORY, 3M CENTRAL RESEARCH LABORATORY, MACROATOM, INC, MARTIN MARIETTA, MONSANTO COMPANY, PALO ALTO VETERANS HOSPITAL, SCHLUMBERGER-DOLL RESEARCH, SIGNETICS CORPORATION, SRI INTERNATIONAL, THE AEROSPACE CORPORATION, UNIVERSITY CITY SCIENCE CENTER, W.R. GRACE & COMPANY, XEROX

U.S. LABORATORIES: ARGONNE NATIONAL LABORATORY, BROOKHAVEN NATIONAL LABORATORY, LAWRENCE BERKELEY LABORATORY, LAWRENCE LIVERMORE NATIONAL LABORATORY, LOS ALAMOS NATIONAL LABORATORY, NATIONAL BUREAU OF STANDARDS, NAVAL RESEARCH LABORATORY, NAVAL WEAPONS CENTER, OAK RIDGE NATIONAL LABORATORY, PACIFIC NORTHWEST LABORATORY, SANDIA NATIONAL LABORATORY, STANFORD SYNCHROTRON RADIATION LABORATORY, WESTERN REGIONAL RESEARCH CENTER

U.S. UNIVERSITIES: AMHERST COLLEGE, ARIZONA STATE UNIVERSITY, BRIGHAM YOUNG UNIVERSITY, BROWN UNIVERSITY, CALIFORNIA INSTITUTE OF TECHNOLOGY, CALIFORNIA STATE UNIVERSITY, CARNEGIE INSTITUTE, CARNEGIE MELLON UNIVERSITY, CASE WESTERN RESERVE UNIVERSITY, CITY UNIVERSITY OF NEW YORK, COLORADO SCHOOL OF MINES, COLUMBIA UNIVERSITY, FLORIDA-ATLANTIC UNIVERSITY, GEORGIA INSTITUTE OF TECHNOLOGY, HARVARD MEDICAL SCHOOL, HARVARD UNIVERSITY, HUNTER COLLEGE CUNY, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, NORTH CAROLINA STATE UNIVERSITY, NORTHWESTERN UNIVERSITY, OHIO STATE UNIVERSITY, PENNSYLVANIA STATE UNIVERSITY, PRINCETON UNIVERSITY, PURDUE UNIVERSITY, RESEARCH INSTITUTE OF SCRIPPS CLINIC, STANFORD UNIVERSITY, STEVENS INSTITUTE OF TECHNOLOGY, TEXAS A&M UNIVERSITY, UNIVERSITY OF ARIZONA, UNIVERSITY OF CALIFORNIA, UNIVERSITY OF CHICAGO, UNIVERSITY OF CINCINNATI, UNIVERSITY OF COLORADO, UNIVERSITY OF GEORGIA, UNIVERSITY OF HAWAII, UNIVERSITY OF ILLINOIS, UNIVERSITY OF KENTUCKY, UNIVERSITY OF MICHIGAN, UNIVERSITY OF MINNESOTA, UNIVERSITY OF MISSISSIPPI, UNIVERSITY OF NEW MEXICO, UNIVERSITY OF NOTRE DAME, UNIVERSITY OF OREGON, UNIVERSITY OF PENNSYLVANIA, UNIVERSITY OF SOUTH CAROLINA, UNIVERSITY OF SOUTH FLORIDA, UNIVERSITY OF WASHINGTON, UNIVERSITY OF WISCONSIN, WASHINGTON UNIVERSITY

FOREIGN: ALCAN INTERNATIONAL LIMITED, CHALMERS INSTITUTE OF TECHNOLOGY, CNRS, ELECTROTECHNICAL LABORATORY, EUROPEAN SYNCHROTRON RADIATION FACILITY, HC ORSTED INSTITUTE, ISTITUTO DI FISICA DEL POLITECNICO, ISTITUTO DI STRUTTURA DELLA MATERIA, KAROLINSKA INSTITUTE, KING'S COLLEGE, LINKOPING UNIVERSITY, MAX-PLANCK INSTITUTE FUR MED FORSCH, MEDICAL NOBEL INSTITUTE, MPG HAMBURG, POLITECNICO DI MILANO, SIMON FRASER UNIVERSITY, UNIVERSITA DI BRESCIA, UNIVERSITA DI MODENA, UNIVERSITA DI ROMA, UNIVERSITAT BIELEFELD, UNIVERSITAT BONN, UNIVERSITY OF SHEFFIELD, UNIVERSITY OF SUSSEX, WEIZMANN INSTITUTE, ZHEJIANG UNIVERSITY

Lawrence Livermore National Laboratory

March 21, 1988

The Honorable Robert A. Roe, Chairman
Committee on Science, Space and Technology
2321 Rayburn House Office Building
Washington, DC 20515

Dear Honorable Chairman Roe:

The Stanford Synchrotron Radiation Laboratoary (SSRL) has been a synchrotron radiation facility since 1974 and judging by its pioneering efforts in the development of novel instrumentation and techniques used for the study of materials, surfaces, and macromolecules, is one of the world's leading synchrotron radiation centers, possibly the premier one.

The research at SSRL, using the two storage rings SPEAR and PEP encompasses most scientific and technological areas and SSRL has served a wide range of users from academic, national laboratories and industry. The laboratory is especially known for its user friendly atmosphere and the support it gives to "the small-science user" whose own resources for support are limited. Currently it is serving some 114 institutions, with over 600 experimental users performing basic and applied research in a diverse range of physical and biological sciences, and advanced materials technologies. State-of-the-art scientific experiments and instrumentation development for the next generation synchrotron light sources are carried out on the PEP storage ring.

The SSRL Users Organization has just had discussions with Dr. Herman Winick, acting Director of SSRL, on the FY89 Presidential Budget for SSRL. The proposed President's Budget is significantly below the requested level. We are extremely concerned. This budget would NOT allow: (1) sufficient operation funds to run the SPEAR storage ring to deliver adequate beam time to SSRL users to maintain its leadership in synchrotron radiation research; (2) any running time for the PEP ring as an R&D device for future synchrotron light sources such as the ALS at Berkeley and the APS at Argonne and (3) new staff hires at SSRL, in spite of an increase in experimental stations recently developed at SSRL by both government and industrial institutions. The budget situation is so dismal that even if the PEP storage ring was not run at all and the staff level was kept at the present level there would not be sufficient funds to run the storage ring SPEAR at its projected level. At this point it is important to understand that insufficient "beam time" on SPEAR was the overwhelming concern expressed by SSRL users in a recent nationwide poll. A major impact of this budget cut is on our young scientists now being trained in the use of these facilities. These people are our future leaders. Without them, more of the focus and leadership of synchrotron radiation research will no doubt shift to Europe and Japan.

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As pointed out in the attached letter to Dr. D. Stevens of DOE incremental increases in operating funds can have a profound effect on the number one problem at SSRL, THE LACK OF SUFFICIENT BEAM TIME. Because certain costs of the laboratory are fixed, independent of beam time, a projection made in the attached letter shows that a tripling of scientific return could be had as a result of about 30% increase in operating funds. This is in line with the recommendations of the committee on "Planning Study for Advanced National Synchrotron-Radiation Facilities" commissioned by the DOE in 1984 which stated as the first priority "To optimize utilization of existing facilities, we recommend providing operations funding, so that such facilities can provide a maximum of beam time in a "user friendly" mode, and continued research funding, so that it will be possible to take full advantage of the facilities."

On behalf of the SSRL users community and the present and future health and competitiveness of synchrotron radiation research in the United States, we strongly urge you to increase the budget level of SSRL for FY89.

Sincerely,

Joe Wong

Joe Wong, Ph.D., D.Sc.
Chairman, SSRLUO Committee

The SSRLUO Committee consists of::
- Prof. F. Bridges (UCSC)
- Mr. R. B. Greegor (Boeing
- Dr. M. Olmstead (UC Berkeley) (VC)
- Dr. J. Stohr (IBM), ex-officio
- Prof. S. Williams (UCLA)
- Dr. R. Bringans (Xerox)
- Dr. J. Kortright (LBL)
- Dr. F. Sette (AT&T Bell Labs)
- Mr. L. Terminello (LBL)
- Dr. L. Wilson (LLNL)

September 16, 1987

Dr. Donald K. Stevens
Associate Director
Office of Basic Energy Sciences
U. S. Department of Energy
Washington, DC 20545

Dear Dr. Stevens,

At a recent meeting, the undersigned Stanford Synchrotron Radiation Laboratory Participating Research Teams (PRT's) identified the lack of adequate beamtime as such a critical issue that it threatens the health of our research programs and the continued support from our home institutions. Simply put, our investments in beamlines are not paying adequate scientific dividends, since they are only functioning a few months per year. From our perspective, an increase of running time from 3 months to 9 months would more than triple the scientific return, due to increased efficiency, and would cost about 30% in additions to the SSRL budget.

We believe that there are few opportunties for such leverage of BES dollars with industry, university and federal laboratory involvement which would be as attractive to you as this one. We urge you to explore the possibilities for additional running time leading to full dedication of the SPEAR storage ring at the time the new injection system becomes operational. It seems that high energy physics priorities are consistent with the suggested change both at SLAC (with the high priority being SLC) and in the nations (with the high priority being SSC). At a time when Japan is considering the construction of 17 new synchrotron facilities, we in the U.S. should at least reexamine agreements reached in the early 1970's to determine whether they are appropriate for the future.

Sincerely,

Marvin J Weber
Marvin Weber
Lawrence Livermore
National Laboratory

Robert Bachrach
Robert Bachrach
Xerox-Research

David Moncton
David Moncton
Exxon Research

W. E. Spicer
W. Spicer
Stanford University

Alexei A. Maradudin
A. Maradudin
University of
California

J. Wong
Lawrence Livermore
National Laboratory

J. Kortright
J. Kortright
Lawrence Berkeley
Laboratory

B. Pate
B. Pate
Stanford University

R D Bringans
R. Bringans
Xerox-Research

MAR-18-88 FRI 11:44 [illegible]

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue, Argonne, Illinois 60439

March 18, 1988

Dr. H. Winick
Stanford Synchrotron Radiation Laboratory
SLAC, Bin No. 69
Stanford, CA 94305

Dear Herman:

I am writing to encourage SSRL to put high priority on running the PEP storage ring for dedicated synchrotron radiation production in FY89. As you know we are expecting delivery in a few weeks of a prototype undulator magnet of the type we will use to generate the high brilliance x-ray beams on the 7 GeV Advanced Photon Source to be built at Argonne. The opportunity to use this device on PEP would provide us an important resource for early R&D activities important to the success of the APS project. For our program, a month of dedicated time would be the minimum necessary as a basis for a joint program. If you are able to fund a longer running period, we could plan to make our undulator available to SSRL for the entire run.

Best regards,

David E. Moncton
Interim Associate Laboratory Director,
Advanced Photon Source

lk

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue, Argonne, Illinois 60439

Office of the Director
Telephone 312/972-3872

August 26, 1987

Dr. Burton Richter, Director
Stanford Linear Accelerator Center
Stanford University
P.O. Box 4349
Stanford, California 84305

Dear Burt,

I was pleased to learn of the plan being developed by Dave Moncton and Artie Bienenstock for a jointly-funded ANL-SLAC program on the PEP storage ring.

Availability of PEP for such R&D work will insure the success of Argonne's Advanced Photon Source by demonstrating some unique scientific applications of x-ray undulator radiation. It will, in addition, strengthen the close relationship between our two laboratories which I would hope will grow during and after the construction of our 7 GeV facility.

I want to assure you of my support for this cooperative program. If there is anything more than I can do to help personally in assuring its success, please let me know.

Very truly,

Alan Schriesheim
Director

AS:hccw

cc: A. Bienenstock
D. Moncton

U.S. Department of Energy The University of Chicago

BOEING AEROSPACE COMPANY
A Division of The Boeing Company

PO Box 3999
Seattle, Washington 98124-2499

16 December 1987
2-3700-HGA-052

Dr. A. Bienenstock
SSRL
P. O. Box 4349, Bin 69
Stanford, CA 94305

Dear Dr. Bienenstock:

This letter is to inform you of the impact that the Stanford Synchrotron Radiation Laboratory (SSRL) has had on the Boeing Company's research in the area of the recently discovered high temperature superconductors and other mateials science efforts. We anticipate that the development of this new class of superconducors will have a significant influence on future aerospace products. The basic structural information that can be gained from x-ray absorption spectroscopy (XAS) experiments performed at synchrontron radiation sources has played a major role in our research effort. In addition to the basic research on superconductors we also have had a number of research contracts in our Physics Technology group which are totally dependent on the availability of synchrotron sources to perform XAS experiments. These projects have included the structure of catalysts, glasses, materials for the encapsulation of radioactive wastes, solutions, and thin film solar cells. Inadequate beam time at SSRL has limited the number of samples that we have been able to process in some of these programs.

Presently the facility is dedicated to materials measurements about 3 to 4 months of the year, even including time for facility maintenance and basic physics experiments using the accelerator, the time dedicated to materials research could be extended to 9 months a year if funds were available for operating the accelerator and the synchrotron radiation laboratory. Many proposals for beam time are presently being turned down or limited due to the unavailability of time on the synchrotron radiation facility. We strongly support SSRL's efforts to obtain increased operating funds to further the U.S. efforts materials research where we are in extremely strong competition with the Japanese. Increased beam time is a cost effective utilization of the capital investment of this national asset.

If we can be of any further help to you, please let us know.

Sincerely,

Dr. H. G. Ahlstrom,
Assistant Director
Engineering Technology

cc: F. Lytle
R. Greegor
L. Mason

BOEING

Lawrence Livermore National Laboratory

December 8, 1987

Dr. Bienenstock
Stanford Synchrotron Radiation Laboratory
P.O. Box 4349
Stanford, CA 94305

Dear Dr. ~~Bienenstock~~ Artie:

It is very satisfying that the University of California/National Laboratories PRT now has three branch lines at SSRL undergoing final characterization and initial experiments. On behalf of the PRT I want to express our thanks to you and your fine staff for helping us to complete construction so rapidly and to begin operations so smoothly. We plan to have all experimental stations (with the exception of the final diffraction/scattering station) in place and commence full operations next year.

Now that our beamlines are a reality, user interest is growing rapidly. The membership of our PRT is especially large, encompassing researchers from all nine UC campuses and three national laboratories. We expect that user requests will greatly exceed currently available beam time for all three branches, thus we will have to restrict usage and be selective in allocating beam time.

The experimental needs and interests of our PRT members for synchrotron radiation are also very diverse, ranging from basic and applied science to advanced engineering and x-ray diagnostics. In many instances the ability to pursue new developments promptly is of extreme importance. Unfortunately this is hampered at present by the limited running time available at SSRL and the variable schedule.

Both increased beam time and more operation throughout the year are highly desirable for our PRT. The DOE and the University of California have made a large investment in the beamlines and experimental facilities at SSRL. More beam time would increase the return on this investment significantly. Other PRTs and the general users must feel similarly. Therefore we ask that you explore ways to increase the amount of running time of SPEAR for synchrotron radiation studies.

The addition of a dedicated injector for SPEAR is a step in the right direction. This should result in more independent and dependable fills and thereby increase the efficient use of available running time Given this excellent synchrotron radiation facility, what more can be done to increase the total operating time and provide more regular service? This is of vital interest to our PRT and other users and I believe :s in the best long-term interests of SSRL and SLAC.

Sincerely,

Marvin J. Weber
PRT Liaison

0234U/mac

cc: C. Gatrousis
R. Kuckuck
W. Shotts
J. Wong
T. Sugihara
M. Fluss

STANFORD UNIVERSITY. STANFORD. CALIFORNIA 94305

WILLIAM E. SPICER
STANFORD ASCHERMAN PROFESSOR
OF ENGINEERING

STANFORD ELECTRONICS LABORATORIES
STANFORD. CALIFORNIA 94305
(415) 497-4643

December 15, 1987

Dr. Arthur I. Bienenstock, Director
Stanford Synchrotron Radiation Laboratories
P. O. Box 4349
Stanford, CA 94305

Dear Artie,

I would like to bring to your attention the adverse effects of minimal running time at SSRL on my own projects at Stanford University. In addition, in the second half of this letter I would like to pass on some of my observations as Acting Director of the Stanford Photon Radiation Laboratory regarding the impact on areas other than my own at Stanford.

My own Stanford program at SSRL involves about ten graduate students and a senior research associate as well as myself. The program is funded at roughly two-thirds of a million dollars a year. When I developed this overall research program in the late 1970's, we had hoped that SSRL would operate approximately fifty percent of the calender year. But in fact because of a number of factors, SSRL has been in operation for much less time. This has resulted in moving back the graduation dates for Ph.D. students one to two years and a considerable loss in other research programs. The programs themselves have been changed to place more emphasis than originally expected on performing experiments with conventional radiation sources rather than on synchrotron radiation even though that quite adversely affects the quality of the work. The senior research associate has been traveling to the University of Wisconsin synchrotron facility for periods of several weeks at a time to make use of available beam time there. This increases the expense and decreases the continuity of work. It is also much more difficult to efficiently involve our graduate students at Wisconsin. However, we are very thankful for being able to do the project at Wisconsin. I am now looking at the possibility for further increasing work at Wisconsin despite this extra expense and the continuity break at SSRL.

Over the years I have made considerable investments relating to SSRL (for example, the DoD portion of Beam Line V). Other investments involve the building of equipment to use at SSRL. I am very concerned that these investments are not being used because of the lack of running time at SSRL. I am also concerned as a thesis director because of the increased length of time necessary to get a Ph.D. Thus, I believe that an increase in operating time at SSRL is very important to utilize the investments already made in this and that this would be very cost effective.

As the Acting Director of the Stanford Photon Research Lab I have been involved in evaluating whether or not a large effort should be placed on completing a planned synchrotron radiation ring which was being funded principally from free electron laser funds. I have found that there are many fruitful projects that Stanford faculty would like to undertake at SSRL but have been hindered in doing so by lack of available time. Included in such projects are such diverse areas as X-ray lithography, studies of polymers by X-ray scattering, and surface chemical studies. Despite the strong need of synchrotron radiation by Stanford faculty, I made the decision that it was better to transfer as many of these projects as possible to SSRL rather than raise the capital and operating costs of another synchrotron source. This decision places still more urgency on trying to increase the running time at SSRL. It has also made me quite aware of the fact that there is much more potential at Stanford for synchrotron radiation if more running time would be available. I mention these experiences with SPRL just to make it clear that there are not only existing synchrotron users such as myself being affected but also potential users who would like to develop useful projects but cannot because of these problems.

Let me close by saying once again that the return on the investments both in these and in the funds necessary to insure more running time at SSRL would be extremely cost effective. The Stanford Synchrotron Radiation Lab works well except for this.

Sincerely,

William E. Spicer

WES:mc

cc: Dr. Ross Bringans - Xerox

Lawrence Berkeley Laboratory
1 Cyclotron Road Berkeley, California 94720
(415) 486-4000 • FTS 451-4000

December 3 1987

Professor Arthur Bienenstock, Director
Stanford Synchrotron Radiation Laboratory
P. O. Box 4349, Bin 68
Stanford, CA. 94305

Dear Artie:

X-ray Spectroscopy using Synchrotron Radiation has played a pivotal role in learning the structures and functions of the Manganese-containing protein complex responsible for oxygen evolution by photosynthetic organisms. As all of the oxygen we breath and use for combustion of fossil fuels is derived from this photosynthetic process, it has obvious importance and relevance to the needs of society.

I stress that this work would not have been possible without synchrotron radiation because only such sources can provide the requisite quantities and qualities of radiation essential to perform the spectroscopy that is the sole mode for probing these sites.

Three of my graduate students will have completed their Ph. D. Dissertations, based on work performed at SSRL, duirng the 1987-1988 academic year. Four more have work in progress that promises to be seriously limited or compromised if we are unable to secure adequate beam time time because of the anticipated reduction in SSRL operations due to funding cuts.

My research activities are largely supported by the Department of Energy's Basic Energy Science program (Division of Biological Energy Conversion) through the Lawrence Berkeley Laboratory. Some additional support is provided by the National Science Foundation. The work is performed almost totally by graduate students from the Departments of Chemistry and Physics at the University of California at Berkeley together with Post-doctoral Fellows. We make abundant use of the facilities at SSRL including those supported by the National Institutes of Health. Accordingly, our activities represent cross-cultural and interdisciplinary research and development at a high level.

We have established several important attributes of the oxygen producing enzyme complex and are now at the threshold of gaining a more detailed understanding of the mechanism by which two molecules of water are converted into one molecule of oxygen. The combination of Synchrotron Radiation and new developments in Molecular Biology are permitting us to make a major breakthrough in this vital process. The absence of adequate beam time will seriously limit our progress.

I hope you are successful in behalf of us all.

Sincerely,

Mel

Melvin P. Klein, Ph. D.
Chemical Biodynamics Division

UNIVERSITY OF CALIFORNIA

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DAVID PIERPONT GARDNER
President

WILLIAM R. FRAZER
Senior Vice President—
Academic Affairs

OFFICE OF THE PRESIDENT
BERKELEY CALIFORNIA 94720

December 8, 1987

Dr. Arthur Bienenstock, Director
Stanford Synchrotron Radiation Laboratory
Bin 69
P.O. Box 4349
Stanford, CA 94305

Dear Dr. Bienenstock:

The synchrotron radiation faculty at Stanford is an important and versatile tool for the faculty and graduate students of the University of California. It provides research opportunities for a growing number of faculty, provides a unique graduate training for students in the sciences and engineering and promotes interaction both with industry as well as with scientists from the national laboratories (LBL, LLNL, etc.). With the recently dedicated new beamline on the SPEAR ring, developed by the University of California/National Laboratories PRT, the importance of this faculty to us has greatly increased.

To make good use of the existing and recently developed beamlines it is important to the University of California that SSRL provide much longer periods of operation than have been available for the last few years. Lack of beam time can hold back faculty research programs six months to a year, significantly delay the completion of graduate student theses and diminish the constructive interactions of the UC faculty with industrial and National Laboratory scientists. The University of California strongly supports efforts to increase substantially the available beam time, on both the SPEAR and PEP rings, in future years.

Sincerely,

WRFrazer

William R. Frazer

College of Physicians & Surgeons of Columbia University | New York, N.Y. 10032

DEPARTMENT OF BIOCHEMISTRY &
MOLECULAR BIOPHYSICS

630 West 168th Street

4 December 1987

Dr. A. I. Bienenstock
SSRL, Stanford University
P.O. Box 4349, Bin 69
Stanford, CA 94305

Dear Artie:

I write to encourage efforts to secure increased beam time on SPEAR for FY89 and beyond. SSRL has been essential to my research effort for several years, and it will continue to be very important until our own beam lines are fully operational at NSLS sometime in 1990. I am particularly excited by our recent advances in the use of multiwavelenght anomalous diffraction in the analysis of protein structures. Several Ph.D. students and postdoctoral trainees in my laboratory depend upon synchrotron radiation for their research, and that availability of adequate time continues to be an impediment.

I might add, as a member of the Proposal Review Panel, that the quality of proposed research at SSRL is generally very high and it seems clear that a doubling of time would translate to enhancement of high quality results. Indeed, I suspect that added time would lead to better running conditions and enhanced efficiency of experimentation such that useful results would rise more steeply than linearly.

Sincerely yours,

Wayne A. Hendrickson

Department of Chemistry
University of California
Berkeley, California 94720

December 8, 1987

Professor Arthur Bienenstock
Stanford Synchrotron Radiation Laboratory
Bin 69, P.O. Box 4349
Stanford, CA 94305

Dear Artie:

I write to express the necessity of beam time at SSRL and the critical need for more frequent access to this facility both for my own research and for other projects at the University of California.

I am studying anomalous scattering of x-rays in materials which exhibit birefringence and dichroism at photon energies near absorption edges. These experiments require intense polarized radiation which can be tuned with high precision to various wavelengths, and they are impossible except with synchrotron radiation. The results may be important to many scattering experiments on all sorts of materials and they are directly relevant to some current applications of synchrotron radiation in studies of crystal structures of proteins.

These experiments involve complicated apparatus which is subject to failure and sample characteristics which can be tested only in the actual experiment. To take maximum advantage of infrequent access (zero to three times a year, with no definite long-range schedule) I have found it necessary to prepare and characterize many specimens of more materials than we can study in order to have alternatives if one or another turns out not to be suitable. A substantial fraction of the total research effort is devoted to this redundant preparation. I expect that these statements are typical of many other synchrotron research projects.

I have found that the slow pace and uncertain schedule have been incompatible with suitable thesis topics for graduate students, and none are involved in my present program. I am acquainted with many graduate students at Berkeley who are working on other projects. As a member of examination and thesis committees I notice the delay and frustration which they experience. In two cases I was forced to decline sabbatical leave visits of foreign scholars who wanted to work with me at SSRL, because the times were wrong for beam time.

Synchrotron radiation offers a rich variety of new opportunities in chemistry. How soon they are achieved will be very much influenced by how much access one can have to the facilities.

Sincerely yours,

David H Templeton

David H. Templeton
Professor of Chemistry

IBM

Almaden Research Center

Dr. Daniel J. Auerbach
IBM Almaden Research Center,
K31/802,
650 Harry Road,
San Jose, CA 95120-6099
Tel. (408) 927-2432

December 3rd, 1987

Dr. A. Bienenstock
SSRL, SLAC Bin 69
P. O. Box 4349
Stanford CA 94305

Dear Dr. Bienenstock,

I am writing this letter to express our concern about the amount of "beam time" available at SSRL. As you know the IBM Almaden Research Center has engaged in a considerable synchrotron radiation effort over the last few years which is centered at SSRL. The synchrotron radiation effort is an important part of the science and technology program of our laboratory and our committment to it is demonstrated by significant financial investments and personnel resources allocated to this program. For example, we have contributed to the improvement of the small angle scattering line (beam line I-4) and are presently involved in the construction of two more beam lines, a powder diffraction branch line (beam line II-2) and the soft x-ray side station on the wiggler beam line X. The present lack of beam time not only jeopardizes an equitable return on this investment, but, more importantly, impedes scientific and technological research which can provide important answers for our laboratory, in particular, and for science and technology, in general. At present about 20 IBM researchers and postdoctoral assistants carry out synchrotron radiation research at SSRL.

In order to be more specific, let me point out some research areas at our laboratory which are affected by synchrotron radiation research and therefore suffer from the unavailability of beam time. The research at the IBM Almaden Research Laboratory most influenced by synchrotron radiation is in the area of thin films, surfaces and interfaces. The high intensity of synchrotron radiation allows the study of very thin films which cannot be done by conventional laboratory x-ray techniques. For example, one of the important problems in magnetic storage is the composition, crystallographic structure and magnetic structure of thin films on disk substrates. Because the magnetic films are often of the order of a thousand Angstroms thick and sometimes have organic and inorganic protective coatings only a few hundred Angstroms thick, the desired information can only be obtained with high intensity synchrotron radiation, using such techniques as x-ray diffraction, extended x-ray absorption fine structure measurements and, in the future, magnetic x-ray scattering. Another example lies in the area of surface and interface science which continues to increase in importance in

IBM's research because of their role in the processing and properties of miniaturized components. At Almaden we have strong programs in understanding the fundamental interactions of atoms and molecules with surfaces and on the properties of very complicated molecules on surfaces and at interfaces with other materials. Programs in this area span from traditional vacuum surface science to electrochemistry to polymer science.

In order to insure the vitality of these programs it is important to have access to a synchrotron radiation facility on a regular basis. In the past SSRL has only operated about 3 months per year and our scientists, even with excellent proposal ratings, have only had less than six weeks of beam time per year to study per program. This is insufficient and I urge you with this letter to explore avenues of increasing the amount of beam time for synchrotron radiation research at SSRL.

Sincerely yours,

Dr. Daniel J. Auerbach
Manager, Physical Science

UNIVERSITY OF OREGON

December 3, 1987

Professor A. Bienenstock
Director
Stanford Synchrotron Radiation Laboratory
P.O. Box 4349 Bin 69
Stanford, CA 94305

Dear Artie:

At the instance of the SSRL Users Executive Committee, I am writing to add to the testimony on the inadequacy of beam time currently available at SSRL.

As you know, our group has conducted research at SSRL since the Laboratory's inception as SSRP. Currently, there are five Ph.D. thesis students in the group; while two are primarily theoretical, all depend on our data from SSRL experiments for their theses. Our success in getting beam time has been abysmal, despite high ratings of our proposals. We are lucky to get one, or sometimes two, experimental opportunities per year. For example, on Proposal 1036 Mp, rated 1.2, we were turned down for beam time during the March 21-May 2, 1987 run and are now given a chance from December 7-21, but entirely during "timing mode" which greatly reduces the usefulness of this run for our purposes. (We had noted this fact in our beam time request).

Our research, while in fundamental atomic inner-shell physics, is not totally esoteric---it has direct relevance to such technological issues as the design of x-ray lasers and questions of energy transport through radiation shields.

The slowdown in thesis research, as well as in ongoing group projects, is costly to graduate students, research supervisors, and research sponsors. Valuable time is lost, and results are sometimes superseded by advances made by colleagues in foreign countries where more ample resources are available. It is out of conviction that the United States must make more synchrotron radiation beam time available to its researchers that I have worked hard to help bring the Berkeley Light Source into being; I am convinced that this will prove to bring about not plain com-

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petition, but rather, a valuable complement to the opportunities that your Laboratory is providing.

I sincerely hope that you will succeed in obtaining the necessary funding to enable fuller utilization of the enormously valuable resource that SSRL constitutes for the scientific community.

Sincerely,

Bernd

Bernd Crasemann
Professor of Physics

c: L. J. Terminello, SSRL-UOEC

UNIVERSITY OF CALIFORNIA, BERKELEY

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OFFICE OF THE
DEAN OF THE GRADUATE DIVISION

BERKELEY, CALIFORNIA 94720
1 California Hall

December 10, 1987

Dr. Arthur I. Bienenstock
Director
Stanford Synchrotron Radiation Laboratory
P. O. Box 4349, Bin 69
Stanford, CA 94305

Dear Director Bienenstock:

The Stanford Synchrotron Radiation Laboratory serves as a vital facility for a number of faculty at the University of California at Berkeley. Currently, at least 6 members of the faculty in the Physics, Chemistry, Chemical Engineering, and Materials Science Departments have active proposals at SSRL, and a number of LBL staff scientists with active proposals are working with UCB graduate students. With the planned Advanced Light Source in Berkeley, we anticipate expanding faculty interest in synchrotron radiation research, and the proximity of SSRL makes it the ideal place to establish this line of research. Also, the students who are being trained now will form the active core of users for the next generation of synchrotron facilities.

A major drawback of graduate research centered around SSRL, however, is the lack of adequate beam time. With an average group able to run only about two weeks each year, the normal learning curve for students is severely disrupted. There is no time to let new students tinker with the equipment, or to do follow up experiments in a reasonable time period. Often the professor and postdoctoral fellows feel they must push students out of the way in order to get the maximum output from such short and far-between experimental runs. Also, short running schedules each year often do not include time during semester breaks, further complicating scheduling. All of these factors severely hamper the graduate research program.

UCB graduate students and faculty are currently studying subjects which range from protein structure and its relation to function to electronic states in semiconductors using synchrotron radiation. I hope you will make every effort to increase the amount of experimental time available so that this important program can reach its full potential.

Sincerely yours,

Joseph Cerny

Joseph Cerny
Provost for Research
Dean of the Graduate Division

JC:ll

SCHLUMBERGER-DOLL RESEARCH OLD QUARRY ROAD RIDGEFIELD, CONNECTICUT 06877-4108 203-431-5000

Schlumberger-Doll Research
Old Quarry Road
Ridgefield, Connecticut 06877

December 10, 1987

Prof. Arthur Bienenstock
SSRL SLAC
Box 4349, Bin 69
Stanford, CA 94305

Dear Prof. Bienenstock,

The current economic climate is putting exteme pressure on all of us to become more efficient and competitive. For Schlumberger, this means obtaining more knowledge about the strucure of geological materials, and developing better tools for obtaining that structural information. I would like to briefly summarize how SSRL helps us work towards that goal, and the types of collaborations created along the way.

The extreme intensity of the synchrotron radiation at SSRL allows us to look at trace elements such as nickel, vanadium, and arsenic in oil source rocks and crude oils at the parts per million level. For oil refineries, these elements are a nuisance because they poison the catalysts used in processing. However, for oil exploration they may be useful as chemical markers. Using the x-ray absorption technique, I have found different chemical forms of these elements at different positions within layered rock samples, and I am currently trying to understand the chemistry behind their deposition and transformation. This work involves a collaboration with Prof. Ralph Zingaro of Texas A& M and Dr. Ron Oremland of the US Geological Survey, Menlo Park.

The unique capabilities of SSRL beam line VI-2 are ideally suited for study of light elements such as phosphorus, sulphur, and potassium. We are probing the chemical nature of sulfur in very heavy oils and asphaltenes in collaboration with Exxon Research and Chevron Oil Field Research. The high molecular weights of these samples make x-ray absorption virtually the only non-invasive technique for obtaining this information, which is important for our ability to produce and refine these more difficult grades of petroleum.

My work at SSRL has naturally led to a large number of collaborations with university faculty and their students and post-docs. I have had 3 post-docs do the bulk of their their experiments at SSRL (Anne-Marie Flank, Marly Eidsness, and Graham George), and on the order of two dozen students visit for a few days or weeks to learn the EXAFS technique. Although the precious nature of beam time makes work at SSRL exciting, it often limits the amount of hands-on experience students can obtain. Furthermore, for those doing thesis work, it is especially difficult to wait months or even years to obtain a missing piece of information or to reproduce an exciting result.

A larger amount of beam time at SSRL would improve both the quantity and quality of research done at your institution. With the current allotment of time, synchrotron radiation research is in danger of becoming a small club which is too hard to break into. I urge you to work to improve both the quantity of beam time as well as the quality and reliability of beams delivered.

Sincerely,

Steph P. Cramer

Stephen P. Cramer

Xerox Corporation
Palo Alto Research Center
3333 Coyote Hill Road
Palo Alto, California 94304
(415) 494-4132

XEROX

December 10, 1987

Professor A. Bienenstock
Director
Stanford Synchrotron Radiation Laboratory
PO Box 4349, Bin 69
Stanford, CA 94305

Dear Professor Bienenstock:

A significant fraction of our research effort involves the use of synchrotron radiation to study new materials and novel material combinations. Access to SSRL's facilities has been very important to us and your assistance over the last ten years has been most appreciated.

We realized early in this research that if we were to carry out experiments with state-of-the-art materials preparation techniques, such as molecular beam epitaxy, we needed to have more beam time than was available at the time as well as the ability to locate our equipment permantly at the storage ring. These were the two main reasons that led the Xerox Corporate Research Group to help build a new undulator beam line. While the new beam line will allow us to achieve many of our goals, the limited beam time which has been available recently will seriously compromise our research efforts.

We believe that there is enormous promise in the full utilization of the novel materials which we are investigating and are frustrated by our inability to obtain sufficient beam time. We strongly urge you to explore all possibilities for increasing the amount of beam time on SPEAR.

Sincerely,

Neville Connell

Neville Connell
Manager, General Sciences Laboratory

Lawrence Berkeley Laboratory
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Materials and Chemical Sciences Division (MCSD)
Mail Stop MCSD 70A-1115

December 7, 1987

Dr. Arthur Bienenstock
Director
Stanford Synchrotron Radiation Laboratory
SLAC Bin 69
PO Box 4349
Stanford, CA 94305

Dear Artie

Recently I have written to Donald K. Stevens concerning the issue of shortage of beam time at the Stanford Synchrotron Radiation Laboratory, and I have attached a copy of the letter I sent him dated September 25, 1987.

I wholeheartedly support the goal of obtaining more beam time at SSRL since its shortage greatly affects many research programs.

Sincerely,

David A. Shirley /bm

David A. Shirley
SSRL User

DAS:bm
Enclosure

Lawrence Berkeley Laboratory
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(415) 486-4000 • FTS 451-4000
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Materials and Chemical Sciences Division (MCSD)
Mail Stop MCSD 70A-1115

September 25, 1987

Dr. Donald K. Stevens
Associate Director
Office of Basic Energy Sciences
U.S. Department of Energy
Washington, DC 20545

Dear Don:

I was recently asked to co-sign a letter to you, with several mmebers of PRTs at SSRL, advocating more support for that facility. Instead, I decided to write this letter. I am writing as a synchrotron radiation user only, and in no administrative capacity.

Our country has a tremendous investment in synchrotron radiation research, and this investment is growing steadily. Much of the investment is distributed in the laboratories of users, and not visible at synchrotron radiation facilities, which are, in a sense, the tip of the iceberg. For this reason, each dollar spent in operating SSRL "leverages" a lot of research. Conversely, for each 8-hour shift that passes without photons at SSRL, research groups throughout the country continue to run on idle. It is very unfortunate, and not cost-effective, to operate SPEAR for SSRL such a small fraction of the time. A marginal increase in the SSRL budget might well increase the operating time, and the science yield, by a significant percentage.

In recent years the high energy and nuclear physics accelerator programs have successfully argued the merits of increasing their operating hours. Congressional committees are sensitive to these arguments, and should be responsive to a DOE request for support to increase the duty cycle of SSRL. Thus as a frustrated user I'd like, first, to request that you use any flexibility you can find to enhance the dedicated running time at SSRL, and, second, to offer my help in developing arguments for more support to this end.

Thanks for your attention.

Sincerely yours,

David A. Shirley

DAS:bm

PANEL 2 DISCUSSION

Mr. **Valentine**. Thank you, Dr. Winick. The several synchrotron radiation sources which you have referred to including the two sources at SSRL, why do we need so many light sources?

Dr. **Winick**. The need and the demand for the kind of radiation and experimental capabilities that these sources provide is huge. You saw the very dramatic pictures presented by Dr. Blume. The fine facility built at Brookhaven is saturated now. We need more capability. We need to plan these new rings and we fully support the planning for these new rings and wish they could come on line earlier. We need them earlier.

An easier and a very cost effective way to get more additional capability is to pay for more running time on existing facilities. At SSRL we are operating at one-half to one-third of capacity due to funding limitations only.

Mr. **Valentine**. It is our understanding that the PEP facility is becoming less attractive as a high energy physics storage ring which its attractiveness as synchrotron Light Source is increasing.

What would it take to fully dedicate PEP as a light source and has this option been discussed and considered?

Dr. **Winick**. Initially, it would take only operations funds to run it. We have two magnificent beam lines, two experimental stations which can act right now and are being used on PEP whenever it runs. It costs approximately $1 million a month to run that machine for dedicated synchrotron radiation production according to present SLAC estimates.

If you truly wanted to make it into a fully-dedicated source with many beam lines, you would have to pay the additional construction cost of the additional beam lines. Those construction costs are estimated at the order of $3 to $5 million per beam line. Those costs are a bit higher probably per beam line than they would be on a newly-planned and newly-constructed and optimized facility such as Argonne is planning which although expensive in the initial construction, it allows the construction of for example, 34 insertion device lines, bending magnet lines, a large number of lines, incremental cost per beam line being less.

However, the real problem is that PEP is not presently available for full dedication. Its availability as stated publicly by Dr. Richter, the Director of SLAC, is for two to three months per year of dedicated synchrotron radiation operation while it also runs for colliding beam high energy physics.

Dr. Richter has stated that the program for PEP for high energy physics was reviewed I think approximately one year or one and one-half years ago with the conclusion that it should be pursued for the order of three more years. I think in two more years it will be reviewed again with an eye toward is it ranking out important good high energy physics science or should it continue.

Many people do project that the interest will be diminishing. In fact, it has diminished already because of the original five high energy physics collicting beam experiments originally installed in PEP, only one will continue operation when PEP recommences operation in October of this year, August of this year.

Mr. **Valentine**. Thank you. Dr. Hartley, in your testimony you indicate that $9.7 million of construction funding is needed for the combustion research facility in fiscal year 1989. Is this in addition to the funding provided in the DOE fiscal year 1989 budget request?

Dr. **Hartley**. In addition to the DOE request, yes it is. This was first funded in 1987 at $300,000; at 1988 for $4.5 million, both of which were Congressional initiatives. The request is to continue that to the full $19.7 million TEC.

Mr. **Valentine**. What is the impact on the program if the DOE request of $3.6 million for this facility is the funding level approved?

Dr. **Hartley**. The $3.6 million is the operating budget for the continuation of programs that are ongoing there now. That is not the construction money for the addition of the Phase II construction money.

Mr. **Valentine**. How much is the construction money?

Dr. **Hartley**. The total construction money is $19.7 million. The $9.7 million is this year's, which is the third year in funding that construction addition.

Mr. **Valentine**. Is that in the budget?

Dr. **Hartley**. No, sir, not in the budget.

Mr. **Valentine**. What is your fiscal year 1989 program budget for the high-temperature superconductivity research?

Dr. **Hartley**. It is scattered from numerous funding sources. I don't have that number but I could provide it to you later. A good portion of it comes from Defense programs funding and on the order of $1 or $2 million probably comes for BES.

Mr. **Valentine**. We would like to have that for the record, if you could.

[The information follows:]

D. L. Hartley
Vice President
Energy Programs

Sandia National Laboratories
Albuquerque, New Mexico 87185

MAR 28 1988

Lottie McCaw-Daniels
Subcommittee on Energy Research
and Development
B-374 Rayburn House Office Building
Washington, D.C. 20515

Dear Lottie,

During my testimony on March 23 concerning the BES budget. Mr. Valentine requested information concerning funding levels and sources for high temperature superconducting at Sandia. The table below responds to that request.

Research Topic	Funding Source	Funding Level in FY88
Solid State Sciences	DOE/MA	700K
Novel Superconducters	DOE/BES	540K
Physics & Chemistry of Ceramics	DOE/BES	500K
High Temperature Superconductivity Research for Applications in Electric Power Systems (proposal for funds in process)	DOE/CE	-0-
High Temperature Superconducting Shielding	DOD/SDIO	375K
High Temperature Superconducting Novel Processing & Devices	Internal Discretionary Research	855K
Superconducting Reconnection Gun	Internal Discretionary Research	375K

Sincerely,

Dan Hartley

DLH:er

Dr. **Hartley**. Certainly.

Mr. **Valentine**. Maybe the same as to this next question also. I realize you might not carry a lot of these figures around. Is this program funded totally within BES or are you getting some DOE funding as well?

Dr. **Hartley** To my knowledge, we have virtually no DOD money. There is other DOE Defense Programs funding in superconductivity at Sandia. There is also some potential funding in this year from Conservation for device fabrication from these superconducting materials.

Mr. **Valentine**. Dr. Blume, it is the Committee's understanding that neutron spectrometers in use at HFBR are now over 20 years of age. I think you alluded to that in your testimony.

These spectrometers are critical to the neutron scattering research presently in progress in the new high temperature superconductors. How much would be required to make a start in fiscal year 1989 to replace these spectrometers?

Dr. **Blume**. We had submitted a plan to the Department of Energy that would call for $4 million in fiscal year 1989 to start this construction. I should say that the construction that we are talking about does not involve any changes in the reactor itself; so that we do not run into the regulatory and safety question that would entail.

We are talking simply about the experimental equipment on the outside of the reactor. We have the potential for increasing the power of those spectrometers by a factor of 10 over what they are right now. Accordingly, many new experiments would be made possible.

Mr. **Valentine**. You suggest Dr. Blume, that additional funding for the NSLS is needed in fiscal year 1989 to cover power cost increases and facility upgrades.

How much of an increase would you recommend for these requirements?

Dr. **Blume**. We would like to see an additional $1 million in operation of the National Synchrotron Light Source. That would enable us to provide for the increased power—it was not an increased power cost, but there will be increased usage of the facility this year as we come out of the shutdown for Phase II. That will enable us to have the operation.

In addition to that, our people will hold the hands of experimenters in that morass of equipment that you saw in that experiment.

Mr. **Valentine**. The Subcommittee is concerned, at least some of the members here are concerned that the x-ray lithography initiative started in fiscal year 1988 is not receiving the proper management attention within DOE.

We would like to have you comment on or have you answer this question. What, in your opinion, needs to be done to assure that the program objectives can be expeditiously and cost effectively achieved from a management standpoint?

Dr. **Blume**. There was one particular problem that was created in this initiative within the Department of Energy. Congress provided the language to start the initiative, but if you looked at the overall bottom line of the Basic Energy Science budget, there was no change in the funding.

As a consequence, there is a plan that is being developed as I understand it, within the Department of Energy.

But they are faced with very serious and difficult choices. If they are to undertake the program that I referred to in my testimony for making an x-ray lithography source, that money would only be available out of the existing program and the problems that I have discussed here would be compounded by an additional $5 to $10 million.

The plans that they have come up with to date involve using the existing programs and moving them more in the direction of x-ray lithography. It is a conservative one. In order to do anything more, there has to be an increase in funding. In order for us to make a synchrotron source we would have to have some funding—and I understand indeed, that the Department of Energy and the Department of Defense are jointly looking at that.

We do have some hope that such a program will go forward in the near future as a result of this collaboration with the Department of Defense and the Department of Energy. I believe that that is the best approach.

Mr. VALENTINE. Thank you. I thank all of you. Mr. Morrison.

Mr. MORRISON. Gentlemen, you all have similar stories and that is you operate extremely popular facilities that are providing the users opportunity. I am not familiar with the fees that you charge for the use of those facilities.

I am wondering if someone hasn't been eyeing that as a potential for raising additional monies to make up for some of these operating shortfalls that you all three have brought to the table. Dr. Blume.

Dr. BLUME. Could I comment on that? When these facilities were established this was a question that was raised. Indeed at that time, it was the policy of the Department of Energy to require full-cost recovery for the utilization of any of these facilities.

This was really counter to what the Department was trying to accomplish at that time, which was to involve American industry in using these facilities and particularly for basic research and applied research.

We do, in fact, recover fees for the use of the National Synchrotron Light Source and the High Flux Beam Reactor when the users are doing proprietary research. In that case, full-cost recovery, which is arrived at in the way you would expect, taking their fraction of the operating costs for the year plus an added factor to take into account the cost of providing the facility in the first place.

However, to ask for fees for basic research would, I think, be counterproductive. We work very hard to get American industry to make a commitment to basic research. It has not been easy. In fact, many industrial organizations have had to be prodded to be of even help to some of the researchers at those organizations to prod their management.

We believe that many of those organizations would simply pull out and stop doing the basic research that we want to see done. So you can view this as seed money that is used to induce American industry into using the facilities. I don't believe that it would be productive.

Mr. **Morrison**. How do you draw the line between basic research and proprietary?

Dr. **Blume**. We have a very simple definition of basic research that we apply to this. It is the research, the results of which the experimenter agrees to publish with dispatch, in the open literature. This definition is very workable because the "with dispatch" is the very important point. Many of the organizations want to study some material whose nature they don't want to reveal for perhaps two years or there about.

By using this definition, we don't have to inquire into why they are doing the research or what they are funding it for. The results are then generally made available to the remainder of the research community.

Mr. **Morrison**. Dr. Winick.

Dr. **Winick**. The American industry makes an immense contribution to these facilities by the construction of beam lines and specialized equipment, which in all cases is available for a fraction of the time to the general user community. So that a small university group can make a proposal and if it gets a high rating at Stanford, for example—the same is true at Brookhaven—they will be assigned by the facility to use this outstanding multi-million dollar piece of equipment with the help of the industrial user who built it, documents it and assists them in carrying out their research.

So, they are providing immense opportunities by their contributions of money and people to construct those beam lines.

Mr. **Morrison**. Dr. Hartley, do you have anything to add to that?

Dr. **Hartley**. The only thing that I would add is that we tend to count the expense the industry has put into staff that they send to the facility. That is a sizeable activity on their part to fund. Also, the in-kind equipment that they leave there or develop specifically for our facilities.

The research facility originally only cost $10 million in fiscal year 1977. We have over $10 million of industry-developed research equipment there now—one-to-one contribution.

Dr. **Blume**. I have a document that has just been put out by Exxon which describes the beam lines that they placed at the Synchrotron Light Source at Brookhaven. It is a very interesting one. These beam lines are used in a variety of research efforts. They are, as has been described, available to general users from universities who come in.

In addition, Exxon actually took three of those beam lines and contributed them to the National Synchrotron Light Source, so that they are owned by the Department of Energy. There was a total of $1.4 million just in those beam lines that was contributed to the facility.

In addition, they remain available to general users. The document is of further interest as it describes the broad range of studies that are carried out by Exxon at Brookhaven. It is characteristic of the other organizations that do this. In some cases—this document was made for their internal use, telling other Exxon divisions what was available to them.

In some cases, in making it generally available, they have deleted information that might be proprietary in this. It demonstrates to me, the fact that these are very useful devices overall; that a large expenditure has been made in putting them forward; and, I believe that the Government is getting its money's worth.

Mr. **Morrison**. Gentlemen, thank you.

Mr. **Valentine**. Mr. Hochbrueckner, do you have questions?

Mr. **Hochbrueckner**. I have just a quick one. I realize that we have to leave here momentarily. Dr. Blume, in your testimony you indicated to the Chairman that your need in terms of the HFBR was $4 million of construction. I assume that there is an associated operating costs?

Dr. **Blume**. Yes. I had mentioned in my testimony that we have a shortfall that amounts to about $3 million, similar to the story that has been told by the others. We have a shortfall of $3 million. With that, we will be able to operate full tilt during the coming year.

I might mention that the reactor is at present, with HFIR down, the premier facility for neutron research so it is essentially the last remaining one until the High Flux Isotope Reactor comes back on line.

Mr. **Hochbrueckner**. Thank you, Mr. Chairman.

Mr. **Valentine**. Thank you, sir. Thank you gentlemen, very much for this testimony.

[Questions and answers for the record follow:]

BASIC ENERGY SCIENCES PROGRAMS

Response to Additional Questions

by the

Subcommittee on Energy Research and Development

M. Blume
Deputy Director
Brookhaven National Laboratory
Upton, NY 11973

April 25, 1988

1. **The FY 1988 Continuing Resolution included $10 million "to initiate a technology program in x-ray lithography aimed at restoring U.S. Leadership in the manufacture of high density computer chips." What role, if any, does Brookhaven National Laboratory (BNL) have in carrying out this Congressional directive, and how is the implementation of this Congressional directive impacting the base programs in synchrotron radiation at BNL?**

The x-ray lithography program at Brookhaven, in response to the Congressional directive, includes a design study for a superconducting synchrotron radiation source. In addition, the operation of NSLS will be directed toward x-ray lithography experiments. A new beam port for the IBM East Fishkill manufacturing unit will be used for future lithography studies. The overall impact of the program will be a loss of users' services for other experimental programs at the Light Source.

2. **Would you support a Congressional directive in the FY 1989 BES appropriation that would direct additional funds to x-ray lithography even if these funds would have to be redirected from the base program?**

The BES-base program is heavily committed to the operation of major facilities and to research on high T_c superconductors. Redirection of funds from this base program to x-ray lithography would cause major disruption, and we plead strongly that this not be done.

3. **Why is it necessary to restart the High Flux Isotope Reactor? Might it not make more sense to provide additional funds for additional instrumentation at the High Flux Beam Reactor at Brookhaven, and accelerate work on the ANS?**

The High Flux Isotope Reactor (HFIR) is a central element in a national isotope production program. In addition, it is of considerable importance in the U.S. neutron scattering effort. For these reasons, strong efforts should be made to restart it. These facts must be balanced against the cost of restarting. If that cost has appreciable impact on other programs, consideration should be given to the course suggested in the question.

4. **You say in your testimony (page 3) that "an additional $3 million in operating funds will be needed for proper operation of the HFBR in FY 1989 and for adequate support for user programs. What additional funds would be required in FY 1989 to initiate the neutron beam lines and facilities upgrade project?**

The first-year request for the HFBR upgrade project is $3.7 million. Any capital funds over $1 million help us begin that project.

5. **What is the shortfall in FY 1989 request for the NSLS operating funds and for accelerator improvement funds?**

An additional $1 million in operating funds and $750,000 to $1 million in accelerator improvements funds are necessary for proper operation of NSLS in FY 1989.

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

Hearing on the Department of Energy (DOE)
FY 1989 Authorization Request for Supporting Research
and Technical Analysis

Republican Member Questions for the Record
for the Hearing of March 23, 1988, for
DR. DANNY L. HARTLEY, SANDIA NATIONAL LABORATORIES

1. In your testimony (page 5), you say that "a Geoscience Research Park at Sandia National Laboratories in Albuquerque has been recommended" and that "[t]he initial phase of this park would be a $19 million Geoscience Research Laboratory and Simulation Facility". Have you formally submitted this proposal to DOE, and if so, what is their reaction?

The value of and need for a Geoscience Research Laboratory at Sandia National Laboratories to service activities within the geoscience and geotechnology communities were initially defined and described to DOE management during the summer of 1985. Management within the Division of Engineering and Geosciences of the Office of Basic Energy Science was supportive of our concept; consequently, Sandia prepared a complete conceptual design along with the Construction Project Data Sheet and submitted the entire package to the Office of Energy Research in the spring of 1986 (FY87) with a request for initial funding in FY88. The project was not included in the FY88 Budget Request, but the construction project was included in the Office of Energy Research Five Year Program Plan (April of 1987) with a start date in FY89. Once again, BES management endorsed the construction project, but the item was not included in the FY89 Congressional Request. At this time, Basic Energy Science planning documents show the Geoscience Research Laboratory as a $20.0 M item with initial funding of $1.0 M in 1990.

2. Please describe in more detail the Geoscience "Simulation Facility", and why it is needed?

The Geoscience "Simulation Facility" would follow and be complementary to the Geoscience Research Laboratory. This set of facilities would constitute a Geoscience "Park" at Sandia National Laboratories. The Simulation Facility would provide a number of large scale geological simulations which would allow the development and/or evaluation of advanced geophysical instrumentation and the investigation of geological stimulation techniques in a well-controlled environment prior to field application. An example of one such simulation facility currently being examined at the laboratory scale is a Geoelectric Simulation Model. This facility can be used to develop both hardware and mathematical models to support surface based geological investigations using electrical potential techniques.

The construction of the Simulation Facilities would be planned for Phase II of the Park and would be configured to meet the needs of collaborative university, industry, and national laboratory alliances.

3. What would be the optimal funding profile for the $19 million construction project?

The cost of the Geoscience Research Laboratory as described in the 1987 Construction Project Data Package submitted to DOE's Office of Energy Research as a FY89 Budget Request is tabulated below.

Cost and Obligation Schedule: (in thousands)

Fiscal Year	Authorizations	Appropriations	Obligations	Costs
1989	$1,000	$1,000	$1,000	$ 500
1990	9,000	9,000	9,000	6,000
1991	6,000	6,000	6,000	5,000
1992	3,200	3,200	3,200	4,000
1993				3,700

4. What would be the annual operating funds required to operate such a laboratory and simulation facility, and who would provide these funds?

The Geoscience Research Laboratory will be a user type facility hosted by the Geoscience Program of the Office of Basic Energy Science (BES). Among primary and most continuous occupants of the facility will be the staff of Sandia actually involved in the more basic research sponsored by BES. Included within this program definition is the Geoscience Research Drilling Office for the Continental Scientific Drilling Program. This core activity expends in excess of $3.0 M annually. Additional beneficiaries of this user facility at Sandia will be the Petroleum and Natural Gas Programs, the Geothermal Program, the Nuclear Waste Management Program, and the Verification and Control Program. Each of these programs has significant geoscience in their program content, are funded at multi-million dollar levels, and will find major value in the facility being recommended.

Since the Geoscience Research Facility is relatively unique within the Geoscience community, programs similar to the ones described at Sandia and located at other national labs, universities, or industry segments will also be beneficiaries of these facilities.

5. What assurances do you have that either industry or universities would carry out research at your proposed Geoscience Research Park?

As operator of the Geoscience Research Drilling Office for the DOE, Sandia currently has intimate technical relationships with a wide range of university and other national lab researchers. In most of these cases there is an overriding need to have a facility in which the scientists and the development engineers can work collaboratively to develop and evaluate new geophysical instrumentation, to test large geological specimens, and to simulate in situ processes (both experimentally and anlytically) prior to actual field experimentation.

In a similar way Sandia heads the Geothermal Drilling Office where we work collaboratively with representatives from the drilling, geophysics, and well service industries to develop and evaluate new instrumentation concepts, lost circulation materials, drill bit technologies, and drilling simulations. In the petroleum industry, Sandia is currently working with Phillips Petroleum to understand the effects of in situ stress modification on oil field production characteristics, with Mobil Oil to develop an improved understanding of electric potential and electromagnetic geophysical techniques, and with numerous oil and gas companies to develop advanced techniques for producing gas from tight sandstones. Several oil companies (e.g., Exxon) and universities (e.g., California Institute of Technology) have requested the use of our large radial arm centrifuge for scaled geological simulations.

These are a few of the examples which demonstrate the existing need for a facility to support a wide range of geoscience investigations and to allow for an efficient transition of the understandings into developed and commercially applied technologies.

6. Please describe Phase II at the Combustion Research Facility.

Phase II of the Combustion Research Facility (CRF) will add 21,200 square feet of laboratory space, complete the existing office building, provide new equipment including two next-generation facility lasers, and provide supercomputer access for in-house researchers and visiting scientists.

Phase II was first submitted to the Department of Energy in FY84. Following validation of the construction plans in FY85, the project was reviewed by members of our user community to assure that Phase II would address their research needs. This review recommended that we modify our plans for facility lasers and provide supercomputer access. In early FY87, our plans were amended to incorporate the recommendations of the review group.

Construction of Phase II was funded initially in FY87 at the level of $300 K; additional funding of $4.5 M was provided in FY88. With continued funding of $9.7 M in FY89 and $4.4 M in FY90, we expect the Phase II expansion to be fully operational by FY91.

7. What are the benefits of completing Phase II at the Combustion Research Facility?

More than a decade ago, in response to a national energy crisis, Sandia proposed to the U.S. Department of Energy a new, ambitious program in combustion research. Our strategy was to apply the rapidly increasing capabilities in lasers and computers to combustion science and technology. As a result of this initiative, the Combustion Research Facility (CRF) was established at Sandia's Livermore location. Designated a "User Facility," the CRF has developed and maintained special-purpose resources in support of a nationwide initiative -- involving U.S. universities, industry, and national laboratories -- to improve our understanding and control of combustion. Through an aggressive visiting scientist program, these resources are made available to nearly 1,000 visitors per year.

Phase II will allow us to meet the energy challenges of the 1990s and to preserve U.S. leadership in combustion science. Growth in our visiting scientist program over the past few years has saturated CRF resources. Phase II will approximately double the available laboratory space to accommodate this growth. Our proposed facility lasers, which have been endorsed by the user community, will enable us to address tomorrow's critical problems in combustion science and technology. Access to modern supercomputers will facilitate the development and application of accurate, predictive models to combustion problems.

RESPONSE TO REPUBLICAN MEMBER QUESTIONS FOR THE RECORD FOR THE HEARING OF MARCH 23, 1988 OF THE SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

HERMAN WINICK, DEPUTY DIRECTOR
STANFORD SYNCHROTRON RADIATION LABORATORY

Question 1. What is the relationship of the PEP synchrotron radiation program and the proposed Advanced Photon Source?

Answer. The PEP synchrotron radiation program has 3 main components, all of which are relevant to the Advanced Photon Source (APS):

1. To provide the opportunity to gain early experience with operation of low emittance 6-8 GeV storage rings (such as the APS) and their associated high brightness beam lines. This is possible because PEP can now operate at the electron energy and emittance planned for the APS and with stored currents that are now about 1/5 that planned for the APS and expected to increase with experience and improvements.

2. To carry out experiments requiring the high brightness [~ 3 x 10^{17} photons/(s,mm^2, mrad^2, 0.1%BW)] now available on the two operational PEP undulator beam lines and the higher brightness that will be available with increased experience with PEP and with the implementation of future beam lines such as the 12 meter undulator beam line proposed for construction in FY1990.

3. To exploit the large circumference, long straight sections and high electron energy of PEP to develop even lower emittance electron beams (down to about 0.6 nanometer-radians at 6 GeV) and higher brightness photon beams [up to about 10^{21} photon/(s, mm^2, mrad^2, 0.1% BW)] to continue to provide unique capabilities for frontier X-ray research and to serve as prototype of a possible 21st century X-ray diffraction limited ring.

The availability of electron and photon beams on PEP that are close to the performance levels planned for the APS offers a most unusual opportunity for extremely relevant APS R&D studies that may be expected to save time and money in the commissioning and experimental utilization of the APS. The management of the APS strongly agrees with these points as evidenced by the letters from Drs. Schriesheim and Moncton which were included with the SSRL testimony to the subcommittee on March 23.

Normally such R&D studies are carried out by computer analyses or by simulations. For example, computer tracking studies are used to learn about field quality, aperture and alignment requirements of low emittance electron rings and the effects of insertion devices on ring performance. Such studies can be pursued very effectively, and the computer calculations can be checked, using the real low emittance electron beams in PEP and prototype APS undulators, as in fact is now planned if funding levels permit dedicated operation of PEP.

Likewise the performance of beam line X-ray optical elements under the intense thermal loading of high brightness X-ray beams can be effectively studied using these beams rather than relying only on computer studies plus simulations in which mirrors, crystals and beryllium windows are subjected to "equivalent" loading by laser and electron beams. It is generally agreed that the utilization of the high brightness beams that PEP can now provide and that the APS will provide will depend on the development of new approaches to X-ray optics and the development of new instruments that can withstand the intense thermal loading. These solutions can be tested and utilized on PEP during the years that APS is in construction.

It is also clear that with the APS and PEP, the US has an excellent opportunity to maintain its present leadership in X-ray synchrotron radiation research in spite of the fact that European and Japanese projects are now expected to come on line before the APS. Furthermore, with PEP's capability to be developed to performance levels that exceed that of all rings now in design or construction, this leadership can be maintained well into the next century.

Question 2. The FY 1988 Continuing Resolution included $10 million "to initiate a technology program in X-ray lithography aimed at restoring U.S. leadership in the manufacture of high density computer chips." What role, if any, does Stanford Synchrotron Radiation Laboratory (SSRL) have in carrying out this Congressional directive, and how is the implementation of this Congressional directive impacting the base programs in synchrotron radiation at SSRL?

Answer: SSRL has had an active X-ray lithography program since 1983. A main goal of this program has been to provide facilities for US industry to conduct exploratory research. In addition an in-house research program in the areas of X-ray resist characterization, radiation damage in masks and X-ray damage in state-of-the-art integrated circuits is underway.

All of this work has been carried out in collaboration with industry. A partial list of companies which have either participated in collaborations or used the facilities at SSRL themselves includes: Intel, IBM, Hewlett-Packard, Micronix, Signetics and Varian. The support to the X-ray lithography program from SSRL's core budget has been about $150K per year including salaries. Industry has contributed money for equipment as well as manpower and supplies.

A limitation on the present program is the amount of beam time available. Because of this the program emphasizes certain fundamental work that can be accomplished within the available time. With more beam time new processes could be tested, modified and retested.

Question 3. Would you support a Congressional directive in the FY 1989 BES appropriation that would direct additional funds to X-ray lithography even if these funds would have to be redirected from the base program?

Answer. Although I believe that X-ray lithography is very important to semiconductor technology and that synchrotron radiation has a vital role to play in these developments, I cannot support a Congressional directive for additional funds for X-ray lithography if Congress provides no new funds for the base program. Redirecting funds from the base program will mean a reduction in the operations budget for SSRL and other synchrotron radiation facilities. At SSRL this would mean a reduction in the amount of time available for X-ray lithography studies. As emphasized in my testimony to the subcommittee on March 23, 1988, the level of "core support" for SSRL operations serving 650 scientists from 35 states is already at a level that will provide the lowest number of operations hours since the start of dedicated operation of SSRL.

Additional operations funding is urgently needed to provide even minimal opportunities for SSRL users to continue the X-ray lithography program and other important programs in basic and applied research including the development of less-invasive coronary angiography procedures, studies of high temperature superconductors, and many programs of direct relevance to environmental and defense interests.

Considering the fact that the present level of funding recommended for FY 1989 is already inadequate to maintain the program on SPEAR, much less exploit the unique opportunities offered by PEP, further reduction in this funding level would be nothing short of calamitous.

Mr. **Valentine.** The Committee will stand adjourned to reconvene on March 29 at 9:30 at Room 2318.

[Whereupon, at 4:50 p.m., this Subcommittee adjourned, to reconvene at the call of the Chair.]

1989 DEPARTMENT OF ENERGY AUTHORIZATION

TUESDAY, MARCH 29, 1988

House of Representatives,
Committee on Science, Space, and Technology,
Subcommittee on Energy Research and Development,
Washington, DC.

The Subcommittee met, pursuant to notice, at 9:35 a.m., Hon. Richard H. Stallings (Chairman of the Subcommittee) presiding.

Mr. Stallings [presiding]. Good morning, ladies and gentlemen. The Subcommittee on Energy Research and Development will come to order.

Today's hearing gives us an opportunity to review a number of energy R&D issues which deserve significant consideration, and which the Subcommittee was not able to cover in the program authorization hearings. Mrs. Lloyd, the Chairman of the Subcommittee, who has to be in mark-up in the Armed Services Committee this morning, wanted me to mention that this hearing covers two topics of great interest to her—the DOE's nuclear physics program and the national x-ray lithography program in which DOE has a substantial role.

Today we shall hear from Dr. Allan Bromley, Henry Ford II Professor of Physics and Director of the Arthur W. Wright Nuclear Structure Laboratory at Yale University, who is an internationally-known researcher and spokesman for the U.S. nuclear physics community. He is going to project the exciting new physics that the U.S. can expect to do on new machines, one under construction at Newport News, Virginia, and the other planned at Brookhaven National Laboratory. Dr. Bromley will be followed by a panel on the DOE x-ray lithography program, which includes a representative of an industry consortium, the Director of the National Synchrotron Light Source at Brookhaven National Laboratory, and the Director of the Aladdin Synchrotron Facility at the University of Wisconsin.

While Chairman Lloyd was going forward with the x-ray initiative in this Committee last year, there was a parallel effort going forward on Armed Services in support of an initiative for DOD. The Defense Science Board has warned the Congress that we must not only avoid becoming dependent on foreign suppliers for tomorrow's microchips from a commercial point of view, but such a dependency is not in our national security interests.

As I understand it, we now have a national program beginning in fiscal year 1988 with $15 million appropriated for the DOD and $10 million appropriated for the DOE program.

Today we shall explore the status and prospects for the DOE program and better understanding of how it complements the DOD effort so we have a truly national program.

After the panel, our other witnesses will address science education needs, the need for an increased petroleum R&D budget, the status of research on ceramic composite materials within Conservation R&D, and the need for a national university program in multiphase flow.

I yield now to our hard-working and distinguished Ranking Republican Member, Mr. Morrison, for his opening remarks.

Mr. **Morrison**. Thank you, Mr. Chairman.

We have heard testimony from the Department of Energy and non-DOE witnesses on various energy R&D programs, including Basic Energy Sciences, Nuclear Physics and Fossil Energy R&D earlier this month. I have been impressed by some of the success stories in these areas, and I also share some of the concerns brought up during these hearings. I am delighted that the private sector and the academic community are here to share their views with us this morning, Mr. Chairman. I look forward to their testimony.

Mr. **Stallings**. Thank you, Mr. Morrison.

Mr. Fawell.

Mr. **Fawell**. I have no statement. Thank you, Mr. Chairman.

Mr. **Stallings**. Thank you.

I am pleased to welcome our first witness, Dr. Allan Bromley from Yale University. Professor Bromley, I welcome you to the Subcommittee. Your written statement, entitled "Frontiers of Nuclear Physics," will be made a part of the record. Please summarize or proceed as you wish.

STATEMENT OF DR. D. ALLAN BROMLEY, HENRY FORD II PROFESSOR OF PHYSICS AND DIRECTOR, A.W. WRIGHT NUCLEAR STRUCTURE LABORATORY, YALE UNIVERSITY, NEW HAVEN, CT

Dr. **Bromley**. Thank you, Mr. Chairman.

Ladies and gentlemen, I am delighted to have this opportunity to appear before you to tell you something about the exciting new developments in nuclear physics, and some of our plans for the future.

This particular time in our history is one of the two most exciting times we have ever had, the last of comparable excitement was back in the early 1930's and with help of Committees like your own, the Congress, and through you, the taxpayers, we have in place and under construction many of the facilities that will allow us to approach these new challenges.

One of the most exciting things is that some of the very best graduate students in the country are choosing to join with us in this adventure we are embarking on.

What I would like to do this morning is to go quickly through some of the newest developments in our field, and then as you requested, discuss briefly the DOE budget in nuclear physics and bring to your attention three outstanding problems that seem to me to demand further attention.

What I would begin with and since most of you think of nuclear physics as a science that is associated with large accelerators, I want to emphasize that is not necessarily true. There is tremendously exciting physics to be done without any accelerator. I want to begin with two examples of that.

After some 10 years, and perhaps we could get some more lights, that's better—after some 10 years of dedicated detector development, Moe and his collaborators at the University of California-Irvine in this past year have detected the rarest process that has ever been observed in a laboratory, that is nuclear double beta decay, and you will notice that the half life of that process is 10 to the 20th years. That is 10 billion times the age of the universe.

NUCLEAR DOUBLE BETA DECAY

- Observed first in 1987 by Elliott, Hahn and Moe at the University of California, Irvine.

- The rarest process, by a large margin, ever observed in a laboratory.

- The two-neutrino mode:

  $^{82}\mathrm{Se} \longrightarrow {}^{82}\mathrm{Kr} + 2e^- + 2\bar{\nu}$

  Halflife: $(1.1^{+0.8}_{-0.3}) \times 10^{20}$ years

  Physical Review Letters 59 2020 (1987)

- The zero-neutrino mode:

  $^{82}\mathrm{Se} \longrightarrow {}^{82}\mathrm{Kr} + 2e$

  not yet observed

  $^{76}\mathrm{Ge} \longrightarrow {}^{76}\mathrm{Se} + 2e$

  Half life$>6 \times 10^{23}$years

  University of California-Santa Barbara

  Lawrence Berkeley Laboratory - unpublished.

FIGURE 1

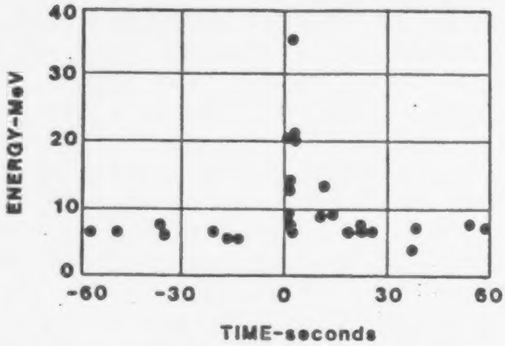
That in itself obviously requires really precise knowledge of the structure of the nuclei involved if we are going to be able to reproduce those results.

Even more exciting, and we know that it is at least 1,000 times less probable, is another kind of double beta decay that has no neutrinos at all. If we find that, and everyone around the world is looking for this in one way or another, we will have the very exciting result that the neutrino has a small but finite mass. This will have the most fundamental implications throughout all of physics.

Strangely enough, the next slide, which is my next example, also relates to the mass of this elusive neutrino. Most of you I think here know that for the first time in 400 years, last year, in the larger Magellanic cloud, we had the first example of that most dramatic and catastrophic of all events in the universe, the gravitational collapse of a giant star in a place where we could see it with the naked eye from Earth. About one day before we first saw that event, two large detectors that were underground looking for the decay of the proton actually picked up neutrinos coming from the Supernova, and there you see the pulse that was observed in the Japanese/Pennsylvania collaboration system. In a few seconds, this collapsing star emitted 10 times more neutrinos than there are neutrons and protons in our entire sun. Some 10 to the 16th of those passed through the 3,000 ton detector, but only 12 were detected.

NEUTRINOS FROM SUPERNOVA 1987A

Data from Tokyo-Pennsylvania Collaboration
Kamiokande Detector



- Supernova emitted 10^{57} neutrinos in a few seconds -10 times the total number of neutrons and protons in the Sun
- Of these, about 10^{16} passed through the detector and 12 were detected
- Provides first experimental proof of stellar collapse
- Pulse shape remarkably well reproduced by Bethe-Brown theoretical model based on nuclear phenomena
- Pulse duration sets upper limit of 15 eV on the neutrino mass.

FIGURE 2

Amazingly enough, from those 12, we have the first definite proof that stars do collapse, that they form neutron stars in black holes, the shape of that pulse is remarkably reproduced by theories that depend on what we know about the nucleus, and therefore anchors down a lot of what before was speculation and that pulse sets the upper limit of the mass of the neutrino at about 15 electron volts.

This is the first real extra solar system neutrino astronomy.

Let me go to the next viewgraph. I want to turn to the question of accelerators. I want to start by giving you a census of the university-based and other facilities in this country. You will note that in 1969, there were 90 university-based programs in the U.S., whereas in 1987, there were only 5 supported by DOE and 11 by NSF. Of those 11 supported by NSF, 3 are now scheduled for shutdown.

US NUCLEAR PHYSICS FACILITIES

1969: 90 university based, accelerator based programs supported by NSF and AEC

1987: 5 university based accelerator based progarams supported by DOE and 11 by NSF

1987: EXISTING FACILITIES

Large tandem Van de Graaffs	*9*
Cyclotrons	*5*
Electron linacs	*3*
Neutron facilities	*4*
Proton linacs	*1*
Total	*22*

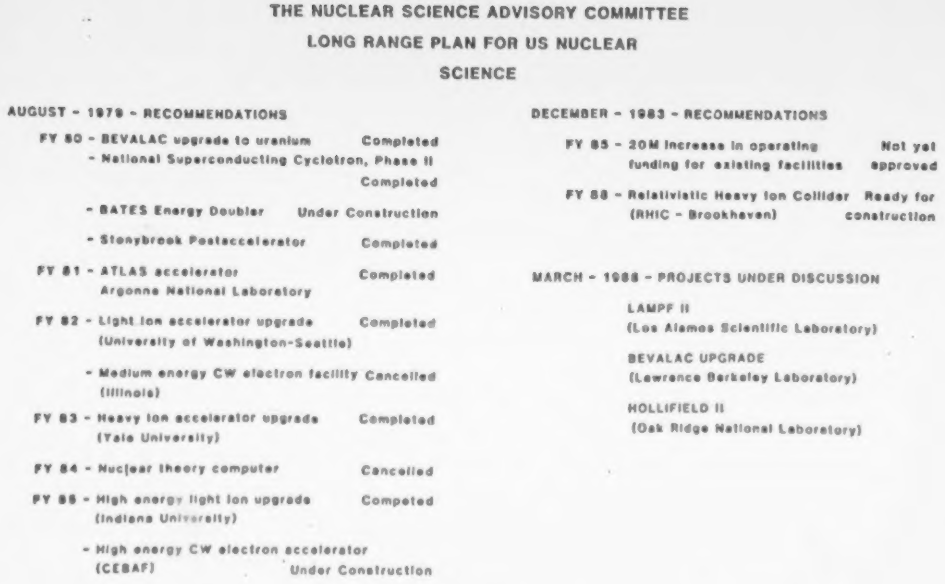
FUTURE FACILITIES

CEBAF (under construction)	*1*
RHIC (proposed)	*1*
LAMPF II (proposed)	*1*
OTHERS	*?*

FIGURE 3

This marks a tremendous condensation of the program. In part, this was to allow the field to respond to new challenges, but in doing so massive a change, it is essential that the change be done in an orderly systematic fashion, if the field is to remain healthy and if we are to be able to respond to new challenges.

My next viewgraph shows you that in the late 1970's, these two agencies asked the Nuclear Science Advisory Committee to make a long-range plan for our science. You will see on the left that from fiscal years 1980 through 1985, a series of projects were given in priority order. This was the consensus of the entire scientific community in nuclear physics.



THE NUCLEAR SCIENCE ADVISORY COMMITTEE
LONG RANGE PLAN FOR US NUCLEAR
SCIENCE

AUGUST - 1979 - RECOMMENDATIONS

FY 80	- BEVALAC upgrade to uranium	Completed
	- National Superconducting Cyclotron, Phase II	Completed
	- BATES Energy Doubler	Under Construction
	- Stonybrook Postaccelerator	Completed
FY 81	- ATLAS accelerator Argonne National Laboratory	Completed
FY 82	- Light ion accelerator upgrade (University of Washington-Seattle)	Completed
	- Medium energy CW electron facility (Illinois)	Cancelled
FY 83	- Heavy ion accelerator upgrade (Yale University)	Completed
FY 84	- Nuclear theory computer	Cancelled
FY 85	- High energy light ion upgrade (Indiana University)	Competed
	- High energy CW electron accelerator (CEBAF)	Under Construction

DECEMBER - 1983 - RECOMMENDATIONS

FY 85	- 20M increase in operating funding for existing facilities	Not yet approved
FY 88	- Relativistic Heavy Ion Collider (RHIC - Brookhaven)	Ready for construction

MARCH - 1988 - PROJECTS UNDER DISCUSSION

LAMPF II
(Los Alamos Scientific Laboratory)

BEVALAC UPGRADE
(Lawrence Berkeley Laboratory)

HOLLIFIELD II
(Oak Ridge National Laboratory)

FIGURE 4

You will notice also that a great majority of those have already been completed. In 1983, noting that many had then been completed, the group was asked to go back and revisit that long-range plan and came up with two new recommendations: one, the highest priority for an increase in operating funding, a step increase of $20 million, and the highest priority for new construction was the Relativistic Heavy Ion Collider at Brookhaven.

Of course, that doesn't end our future planning and when this group revisits the long-range plan in the not too distant future, I have listed several new facilities that will be under consideration.

The important thing is, however, that the existence of this plan since before 1980, and the fact that the agencies and the Congress and the community have followed the plan has given us the stability and a base for long-range planning that has been absolutely essential.

Let me now give you a few illustrations of some of the work that can be done with these facilities and show you examples of them.

One of the most exciting developments during the past year and a half has been the fact that new accelerators, new detectors and new techniques have worked a renaissance in our understanding of the structure of nuclei. It is comparable to what happened when the laser was developed and gave us access to the structure of the atom.

This picture plots the spin vertically against the number of neutrons in a particular rare earth element, dysprosium, and up until 18 months ago, our experimental techniques were limited to that shaded region. Today, we can cover that entire diagram and more.

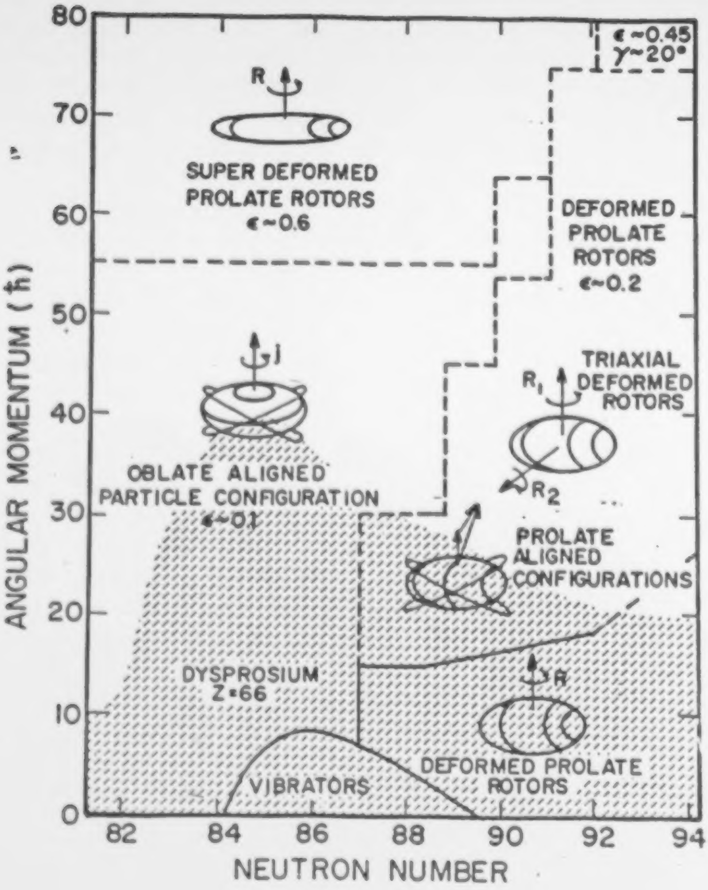

ANGULAR MOMENTUM (ħ)
NEUTRON NUMBER
0
10
20
30
40
50
60
70
80
82
84
86
88
90
92
94
R
SUPER DEFORMED
PROLATE ROTORS
ϵ~0.6
ϵ~0.45
γ~20°
DEFORMED
PROLATE
ROTORS
ϵ~0.2
j
TRIAXIAL
DEFORMED
ROTORS
R1
R2
OBLATE ALIGNED
PARTICLE CONFIGURATION
ϵ~0.1
PROLATE
ALIGNED
CONFIGURATIONS
DYSPROSIUM
Z=66
R
VIBRATORS
DEFORMED PROLATE
ROTORS

Figure 5

The important thing is, I don't want to go into the details, the important thing is that the shape of the nucleus changes as one goes to different regions of that diagram. As you spin the nucleus faster, as you add more valence nucleons.

The most important development of the last year has been the recognition from theoretical studies that the change takes place as a phase transition. The analog in the nuclear fluid to what happens in water when you freeze it or boil it, and of course, if we can detect those, and a lot of people are looking for them now, it will illuminate a whole new area of behavior of quantum fluids, far outside of nuclear physics.

Another major development has been the recognition of fundamental symmetries underlying the behavior of nuclei. Much of the progress that is made in fundamental science comes from a recognition that there are definite symmetries that determine what we observe. In the nuclear case, these symmetries determine how pairs of neutrons and protons build up to form the structure. Within the last six months, in fact, we have also had the first hints that there may be an equally important unification using these same symmetry techniques of our understanding of how nuclei interact.

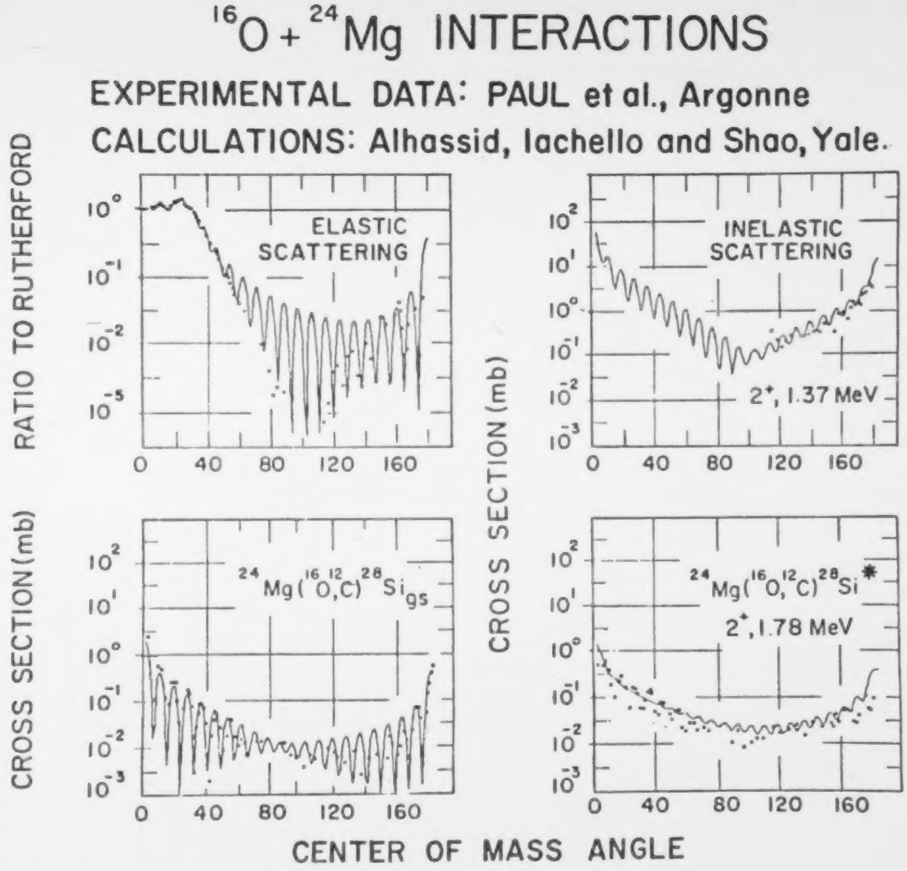

$^{16}O + ^{24}Mg$ INTERACTIONS
EXPERIMENTAL DATA: PAUL et al., Argonne
CALCULATIONS: Alhassid, Iachello and Shao, Yale.
RATIO TO RUTHERFORD
ELASTIC SCATTERING
10°
10⁻¹
10⁻²
10⁻³
0
40
80
120
160
CROSS SECTION (mb)
INELASTIC SCATTERING
2⁺, 1.37 MeV
10²
10¹
10⁰
10⁻¹
10⁻²
10⁻³
CROSS SECTION (mb)
$^{24}Mg(^{16}O,^{12}C)^{28}Si_{gs}$
$^{24}Mg(^{16}O,^{12}C)^{28}Si^*$
2⁺, 1.78 MeV
CENTER OF MASS ANGLE

FIGURE 7

On the one hand, we have unified our pictures of the structure. Now it looks as though we can also treat the interactions on the same basis. These are very important developments.

They are typical of the work that gets done with the smaller accelerators that are found on university campuses and the national laboratories and I want to emphasize that the work done with these machines is complimentary to that done with the higher energy facilities to which I am going to turn in a moment, the ones that the Chairman mentioned.

In order to understand the new results from the big facilities, you must have the results from the small ones. Progress is made by synthesizing the results from a wide spectrum of different experimental approaches.

Let me now show you a few of the recent facility changes. This is one from my own laboratory at Yale.

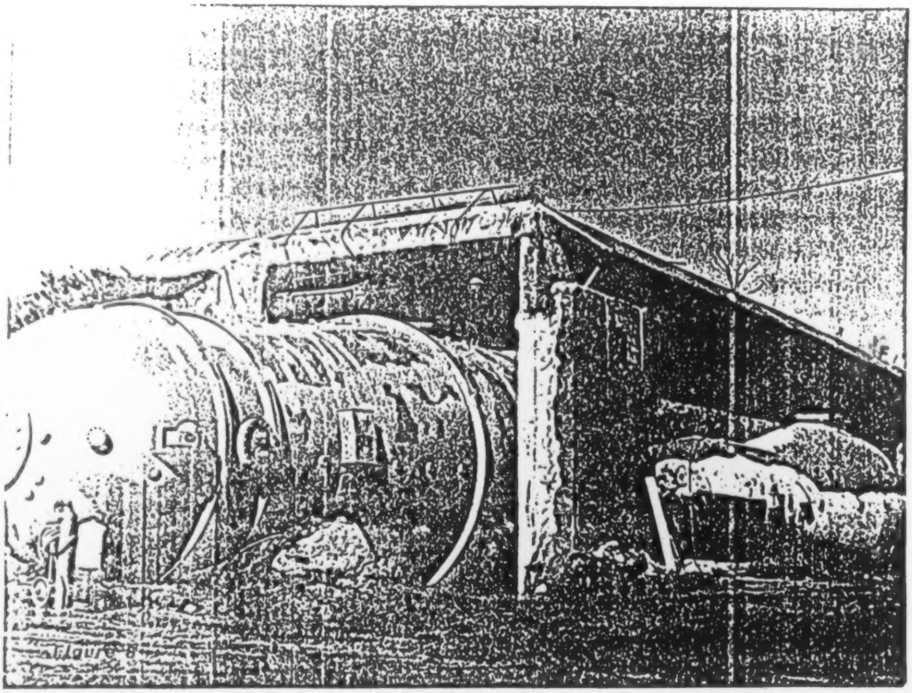


FIGURE 8

You will notice that blue and yellow tank that looks like a submarine off on the right. In 1966, when that was dedicated, it was the world's most powerful precision electrostatic accelerator. We have just finished replacing it with what you see being moved into the laboratory which is the first of an entirely new class of machines. The old Emperor-class machine operated to 10 million volts. The new ESTU has already been operated up to over 22.5 million volts. That is DC voltage. You can think of it as 22.5 million flashlight cells strung in a line.

To give you a better feeling for what is inside the tank, here is a view taken inside by my colleague, Peter Parkers, standing on the floor of the tank, under the high voltage terminal, which operates this 22.5 million volts, looking down the length of the electrostatic column.

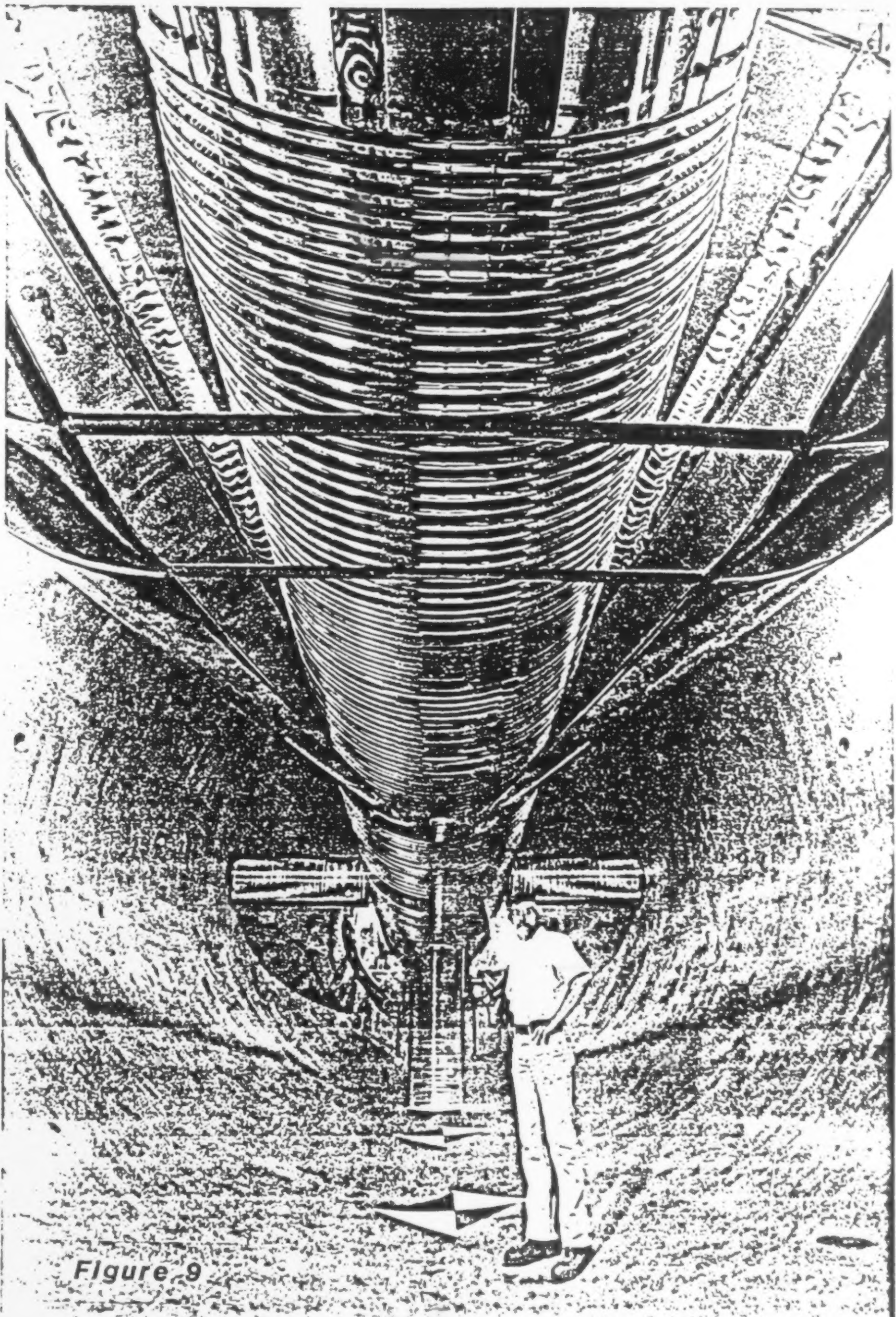


FIGURE 9

This is one of the three most powerful precision machines available anywhere in the world.

This shows you a national lab facility, that is also in the frontiers. This is at the Argonne National Laboratory. It is the superconducting linear accelerator that is being injected by a smaller electrostatic machine. It is the so-called ATLAS facility.

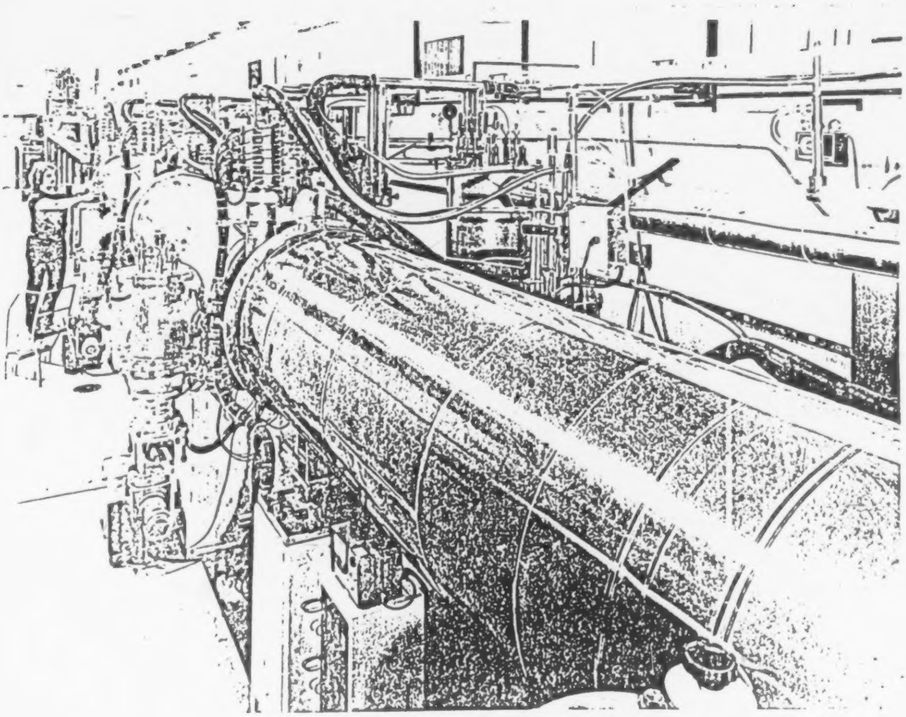


FIGURE 11

This is one that is supported by the NSF. Those two are DOE facilities. This is the National Superconducting Cyclotron Laboratory at Michigan State University with its builders. That is the K800 cyclotron with its builders clustered around it. It is NSF. The other two were DOE.

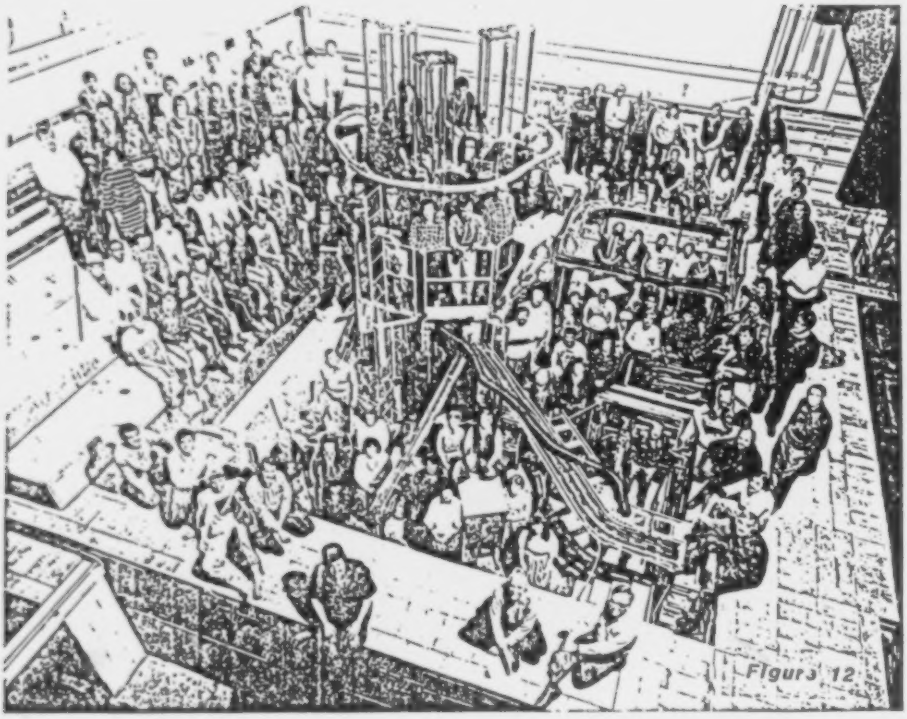


Figure 12

I have to emphasize that all that I have talked about so far with these smaller facilities of the kind I've just shown you really concerns the nuclear surface, its shape, its behavior and how neutrons and protons move in it. If we really want to look inside the nucleus, deep inside, we have to have a probe that reaches throughout the entire nuclear volume, high energy electrons constitute such a probe.

On this slide, I show you on the bottom first what we expect if you scatter high energy electrons off a proton and at the top, off a nucleus. In the proton, you see at low energy you have elastic scattering off the proton behaving as an entity on its own. As the energy increases, some of it can be used to excite the proton to its own quantum excited states, the delta, the N-star resonances and so on. As the energy of the electron increases, eventually you begin to probe inside the proton and see the individual quarks of which it is constructed.

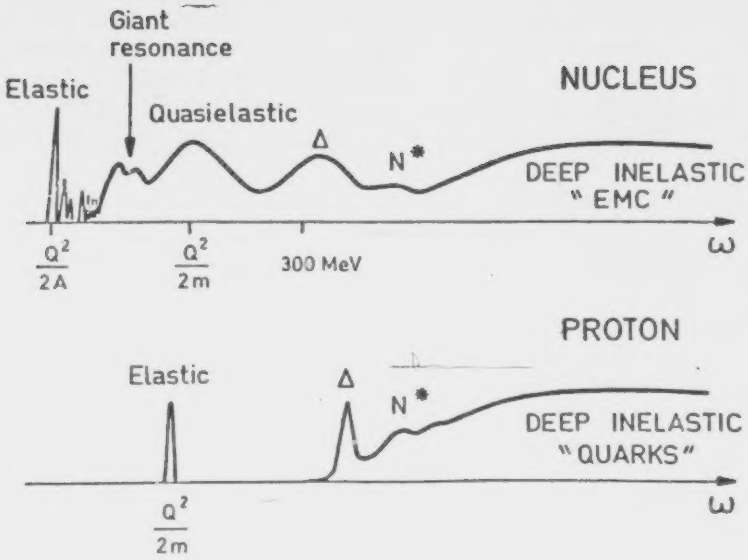

Giant resonance
Elastic
Quasielastic
NUCLEUS
Δ
N*
DEEP INELASTIC
" EMC "
$\frac{Q^2}{2A}$
$\frac{Q^2}{2m}$
300 MeV
ω
PROTON
Elastic
Δ
N*
DEEP INELASTIC
"QUARKS"
$\frac{Q^2}{2m}$
ω

FIGURE 13

In the upper part, if you do the same thing with a nucleus, you see first of all elastic scattering at low energy then the giant resonance where the neutron and proton fluids oscillate against one another, then the spore of these delta and N-star resonances inside the nucleus and finally again you begin to see quark effects.

It is this transition between matter that we call hadronic, the kind of matter we are all familiar with, that makes up the universe as we know it, and an entirely new kind of matter, quark matter, that makes these facilities particularly exciting.

We are going to be able to trace the behavior of matter as it changes from what is familiar to us into an entirely new kind of matter. In order to do that, we need very-large, high-energy electron facilities. This was identified in the first NSAC long-range plan and happily under construction at Newport News, we now have the continuous electron beam accelerator facility, CEBAF. The next slide shows you an overview of that. It will give us in this country a facility that is absolutely unique in the world.

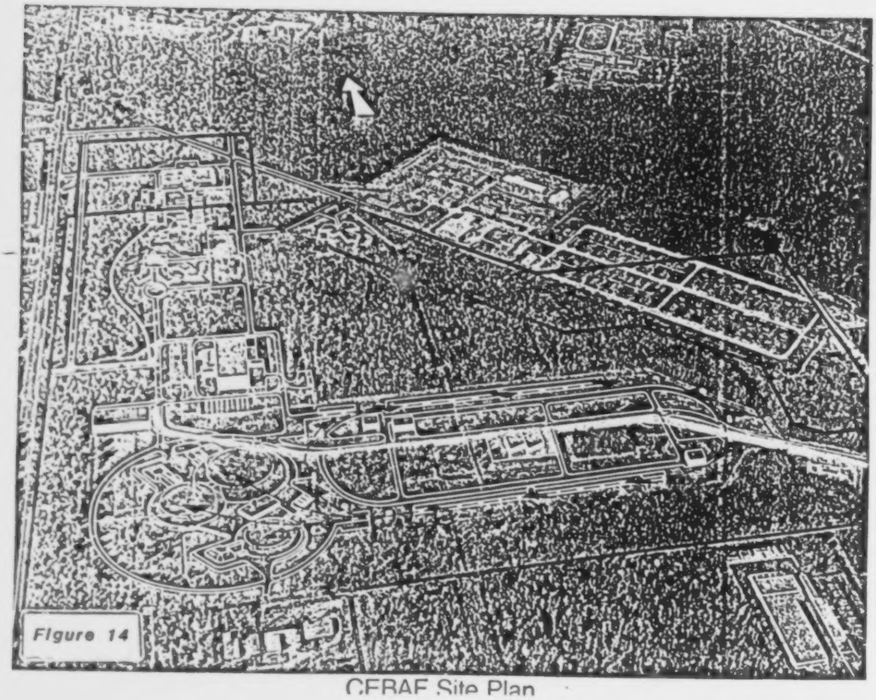


Figure 14

CEBAF Site Plan

Here you see an aerial view of the site and in the long oval race track, there are two 500 MeV superconducting linear accelerators, the beam is circulated four times around that race track to get 4-GeV electrons, and then they are directed into one of the three target areas which you see as those circular regions at the lower left.

The next slide simply reminds you of what some of the major reasons were why this was the highest priority for new construction in the community. First of all, it does address fundamental problems. It really allows us to study this vital transition region between hadronic and quark matter. Also the electron interactions are the best understood of any in fundamental physics, which allows us then to really extract what we want to learn about the nucleus from studies with electrons.

SCIENTIFIC MOTIVATION FOR CEBAF

- CEBAF addresses fundamental problems in nuclear physics
  - The role of mesons, excited baryons and quarks in nuclei
  - The strong force, including non-perturbative features of QCD
  - The effect of the nuclear medium on nucleon structure and quark interactions

- Electrons are precise, versatile probes of nuclear structure
  - Small cross section: $\sigma \sim 10^{-40}$ cm^2
  - Well understood interaction: QED (perturbative)
  - Probe the entire nuclear volume
  - Variable energy and momentum transfer

- CEBAF energy range explores a transition region
  - Conventional nuclear structure studies
  - Non-perturbative QCD (mesons and baryons)
  - Quark structure in nucleons

- Over 20 proposed experiments

FIGURE 16

They do probe the entire nuclear volume and tell us what is going on inside. We have here our first glimpse of this quark-gluon plasma, a new state of matter. There are other ways of getting at that. I want to show you the next one.

The next slide illustrates a number of things. What I am showing you here is the so-called equation of state for nuclear matter. The question that many of us are asking now a days is how does nuclear matter which makes up over 98 percent of the entire known universe, how does it behave under extreme conditions. I plot here temperature against the density. You can see where the blue line starts is where ordinary nuclei are. There are many interesting things in this diagram but I only want to point to one or two.

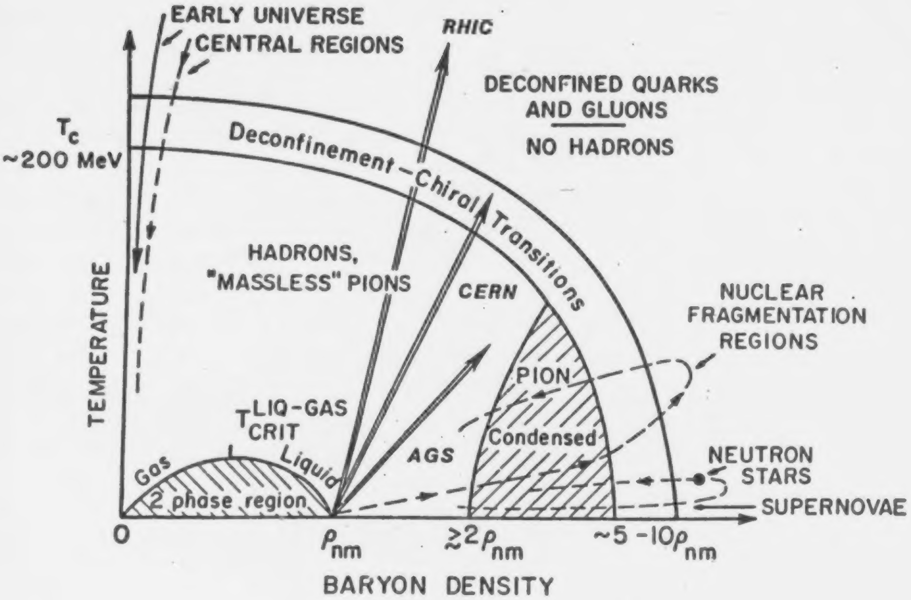

EARLY UNIVERSE
CENTRAL REGIONS
RHIC
DECONFINED QUARKS AND GLUONS
NO HADRONS
T_c ~200 MeV
Deconfinement–Chiral Transitions
TEMPERATURE
HADRONS, "MASSLESS" PIONS
CERN
NUCLEAR FRAGMENTATION REGIONS
PION Condensed
$T_{CRIT}^{LIQ-GAS}$
AGS
Gas
Liquid
2 phase region
NEUTRON STARS
SUPERNOVAE
0
ρ_{nm}
$\gtrsim 2\rho_{nm}$
$\sim 5-10\rho_{nm}$
BARYON DENSITY

FIGURE 17

Inside that loop is where we have hadronic matter, the matter we are familiar with, the matter of which we are constructed. Outside is quark matter. We know that this transition has been crossed at least twice in the universe. Two-tenths of a second after the initial bang of creation, we know that as the fireball cools down and cools down past about two trillion degrees, the quark-gluon plasma condensed into hadronic matter, and that happened at very low density and at very high temperature. That is over on the extreme left.

We also know that during Supernova explosions of the kind we have seen in 1987A in the Magellanic Cloud, at low temperature but at very high density as gravitational contraction pushes the nucleons into one another, again we cross through the transition from hadronic into quark matter.

The question before us is: Can we do this in controlled fashion so we can study this transition in detail? Can we look for entirely new kinds of matter, new ways to release energy? The answer is yes, we can.

During this past year, we have had the good fortune to be able to study with two accelerators, one, the Alternating Gradient Synchrotron at Brookhaven labeled AGS, and one, the European Center for Nuclear Research Facilities at Geneva, labeled CERN.

We have been able to do preliminary work and as you can see, AGS doesn't have enough energy to take us out to the transition. CERN just gets us barely into the transition. We have the opportunity, a unique opportunity in this country, if we grasp it, to build a facility, the Relativistic Heavy Ion Collider, which for the first time will take us firmly out into the quark-gluon area, into the new domain, and allow us to study that in really controlled fashion, to recreate the conditions that existed a fraction of a second after creation, to recreate the conditions in the dying seconds of a collapsing star. This is rather remarkable that we can do it but it stands as one of our challenges at the moment.

This is an artist's conception of what happens in this approach that we are going to use where you smash one heavy nucleus into another one.

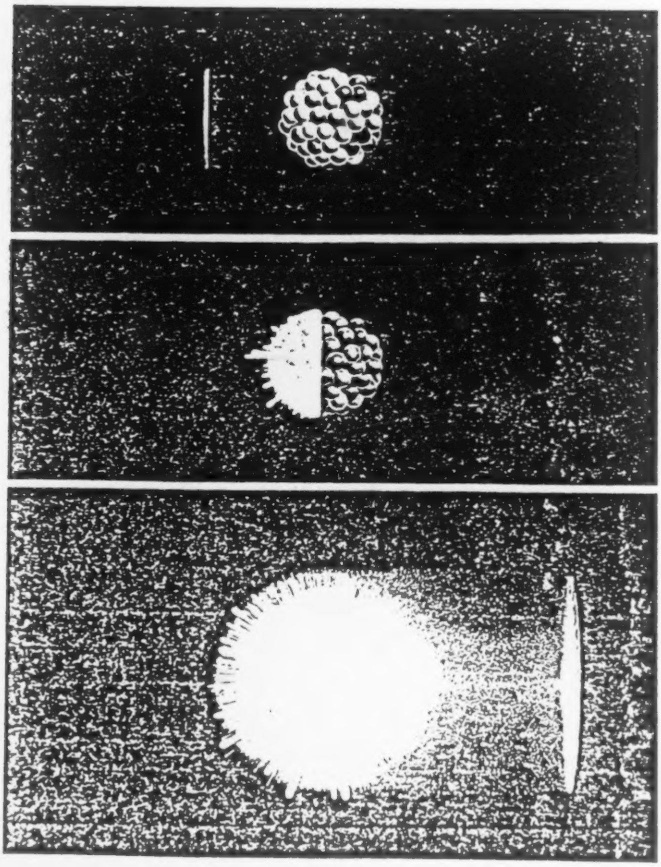


FIGURE 18

On the top, coming in from the left is the uranium nucleus moving at relativistic velocities. It is moving so fast that relativity has shrunk it into a disk, and it is about to hit an uranium target nucleus sitting at rest. As the two start to inter-penetrate, they are heated to enormously high temperatures. As they pass through one another, you have a region, the target region, that is enormously hot, that is full of the fragments of the original neutrons and protons, the same thing in a projectile region and in between in what is called the fire tube, is where we hope to be able to find the pure quark-gluon plasma. The question is, what kind of a facility do you need to give access to that fire tube. The next slide shows you.

RELATIVISTIC HEAVY ION SCIENCE

AT BROOKHAVEN ENERGIES - 15 GeV/nucleon
~ 5 GeV/nucleon C.M.

a) Projectiles are completely stopped in the target nuclei

b) Densities about 4 times normal are attained

c) Kaon/Pion ratios are greater than 20% higher than in proton-proton collisions--evidence for kaon distillation and high baryon densities

AT CERN ENERGIES - 200 GeV/nucleon
~ 20 GeV/nucleon C.M.

a) Target nuclei are partially transparent

b) Energy densities of 1 GeV/(fm)^3 are attained ~ 7 times normal in nuclear matter

c) Hot core more than doubles in size--target explodes--before pions uncouple

d) J/Ψ resonance is observed as evidence for production of heavy quarks and is damped by 65% in central collisions by color screening--evidence of approach to quark gluon plasma.

AT RHIC ENERGIES - 100 GeV on 100 GeV
~ 200 GeV/nucleon C.M.

a) Energy densities in range 3-10 GeV/(fm)^3 attainable--20 to 70 times normal

b) Densities 5 to 10 times normal are attainable

c) The quark gluon plasma is fully developed

d) The possibility of entirely new kinds of matter exists

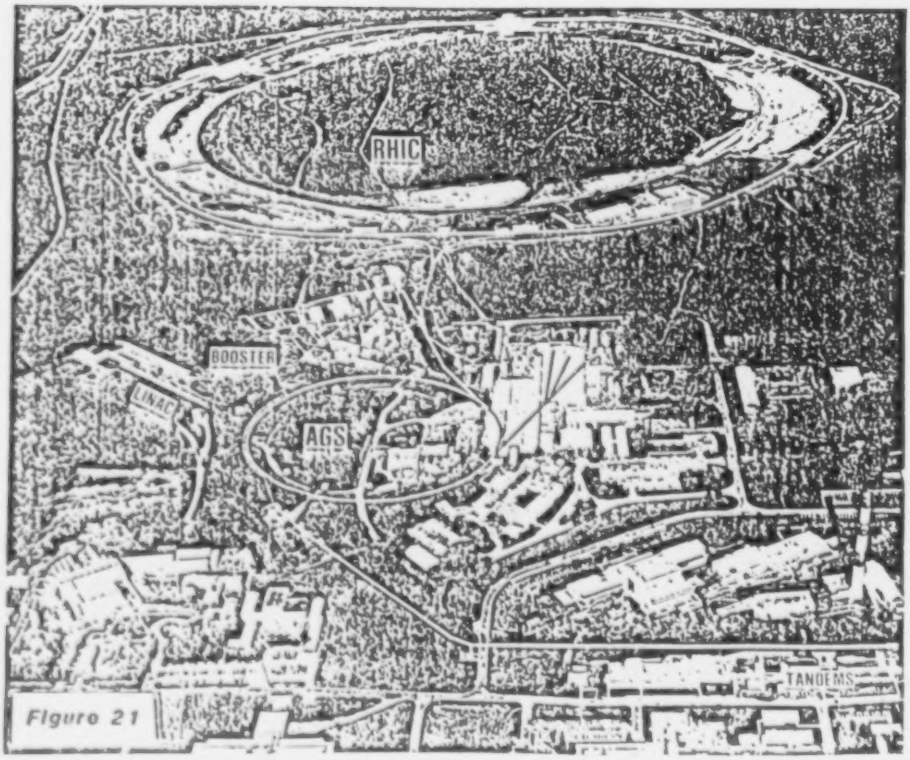
e) Quantum chromodynamics can be tested in its perturbative limit.

FIGURE 19

Fortunately, we have at Brookhaven—let me show you before we go to the photograph. Here, I show you what was done at Brookhaven, at CERN, and what we think we can do at RHIC. You don't have to worry about all the detail on here. I just want to point out a few key points.

At Brookhaven, you see we have 15 GeV per nucleon energies. That corresponds to a useful energy of only 5 GeV in the center of mass. At CERN, we have 200 GeV. That corresponds to 20 GeV only in the center-of-mass, the useful energy. At RHIC, the Relativistic Heavy Ion Collider, we will have 200 GeV in the center-of-mass, fully 10 times more than CERN is ever going to be able to get with their existing facilities. It is going to be a unique facility, completely unique in the world. As you see, whereas we have a number of interesting new discoveries at Brookhaven, at CERN, that make this field clearly one of the most exciting frontiers of our science, with RHIC, you see for the first time we are going to see the quark-gluon plasma fully developed. We have the possibility of finding entirely new kinds of matter and we are going to be able to test quantum chromodynamics, which is the newest of our global theories to understand the fundamental structure and the life history of our universe.

Fortunately, we have at Brookhaven the hardware and the civil engineering left over from the Colliding Beam Accelerator, which was terminated about five years ago. We are able to use that hardware and that development to constitute fully one-half the cost of the new facility that is being proposed. That makes it essentially impossible for any other group anywhere else in the world to come up with such a cost effective proposal, because half of the cost is already in place, half of the hardware is already in place.


RHIC
BOOSTER
LINAC
AGS
TANDEMS

Figuro 21

What happens here is the beam starts off in the lower right, is carried 1,000 feet in a transfer line into the venerable old Alternating Gradient Synchrotron, accelerated to 15 GeV per nucleon, and if we are able to proceed with RHIC, as I hope we can, it will be injected into this large ring that is left over from CBA and accelerated in both directions to 100 GeV per nucleon and these beams will collide at six places around the ring. That's where we will hope to see all these new phenomena.

This next slide simply reminds you of why we are doing this, why we want to do this. Really, our fundamental problems are addressed here. In nuclear and particle physics as well as in astrophysics. The transition into quark matter, the recreation of the early moments of our universe, the last moments of the collapse of massive stars, the understanding of how nuclear matter behaves under extreme conditions.

SCIENTIFIC MOTIVATION FOR RHIC

- RHIC addresses fundamental problems in nuclear and particle physics as well as astrophysics
    - the deconfinement of quarks in nuclei
    - the creation of the quark gluon plasma
    - the recreation of the early moments of creation
    - the physics of gravitational collapse of massive stars
    - the equation of state of nuclear matter
    - the possibility of entirely new kinds of matter
    - the strong force including non-perturbative QCD

- Heavy ions are uniquely powerful in such studies
    - ever increasing energy is delivered to volumes large enough to contain many nucleons (quarks) and thus permits the possibility of collective phenomena
    - wide range of projectile and target species helps in the isolation of specific interaction features and phenomena

- In using esentially all of the prior investment in CBA , RHIC is a remarkably cost effective proposal with sufficiently high energy to give clear access to the central rapidity region-the quark gluon plasma

FIGURE 23

There is the possibility of entirely new kinds of matter and we really are going to be able for the first time to try and understand how the strong nuclear force that gives us nuclear energy behaves from a deep fundamental sense.

We also have the situation here that heavy ions are uniquely powerful because, in contrast to what happens in particle physics, about which you have heard previously. In particle physics, you try to put ever more energy into ever smaller volumes in the hope that some of the energy will materialize into heavier and heavier particles. In nuclear physics, you try to put ever more energy into quite large volumes so that you can find new collective phenomena involving many quarks and many particular particles.

Finally, the last point is the one I mentioned before. Because of the prior investment that the U.S. taxpayer has made in CBA, an investment that will be wasted if we cannot proceed with this kind of facility that will use it, we can make a remarkably cost effective proposal.

Now, the next slide just illustrates that there are things out there on the horizon.

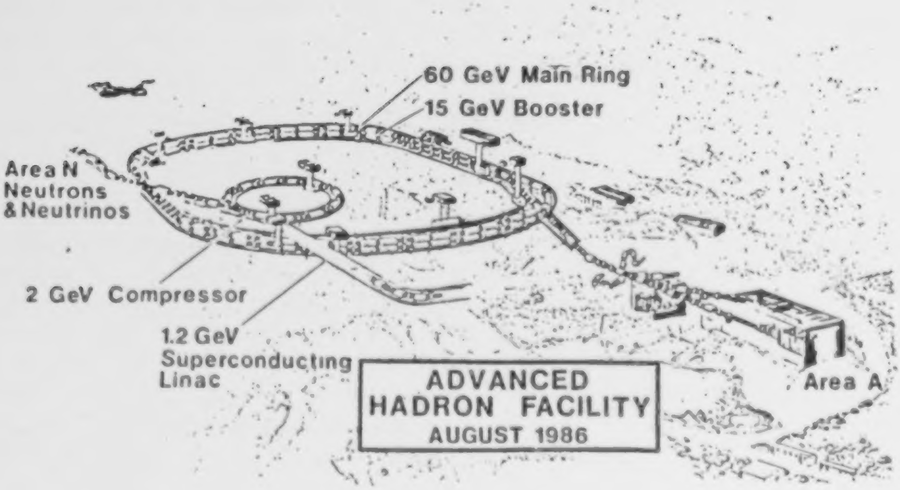

60 GeV Main Ring
15 GeV Booster
Area N
Neutrons
& Neutrinos
2 GeV Compressor
1.2 GeV
Superconducting
Linac
ADVANCED
HADRON FACILITY
AUGUST 1986
Area A

FIGURE 24

Everything I have talked about so far has been in the direction of moving to ever higher energies. There is another frontier, a totally different one, and that is the move to high intensity frontiers. If you want to look at very rare processes, then you need very intense beams of particles, not only direct protons but also secondary particles, strange particles, charmed particles, and in order to make those you need the kind of accelerator system that is shown here, that was designed at Los Alamos. This is not yet in the long-range plan for nuclear physics in this country. It is still in the design and discussion stage, but it would allow us to look at matter in a way that is complementary to everything we have now: the protons, the heavy nuclei, the electrons.

Here we can use kaons, other of the strange and charmed particles, to look at nuclei in entirely different ways, and these are the things that will be discussed in the next round of the development of the long-range plan.

The next one, please.

In asking me to appear here this morning, Mr. Chairman, you asked me to comment on the nuclear physics budget in DOE for Fiscal Year 1989. I am delighted to do so.

DEPARTMENT OF ENERGY
NUCLEAR PHYSICS BUDGET
FY 1989

- Total FY1989 Presidential request is $264.1 million representing a 7.75% increase over FY1988 — of which 4.5% represents an increase from 33.5 to 44.5 million in CEBAF construction funding.

- This represents a generous support of this science in a year when many areas are experiencing deficit reducing budget cuts.

- BUT, there are three problem areas that are of major importance to the future of this science. All reflect departures from the NSAC long range plan.

FIGURE 26

Let me first of all note that the Presidential request is for a 7.75 percent increase, 4.5 percent of that going to CEBAF construction, and I think the first thing that I have to say both personally and on behalf of my community is that this does represent generous support of the field during a year when a great many areas are experiencing deficit-reducing budget cuts. There is no question about that. But I feel that I must bring to your attention three problem areas that are of great importance to the future of our science, and all of them are problems that have arisen because we have departed from the long-range plan laid out way back in 1979 by the Nuclear Science Advisory Committee.

The last viewgraph simply lists these problems that I would like to bring to your attention.

PROBLEM AREAS

- At a time when outstanding graduate students are turning, in increasing numbers, to nuclear physics and, when several universities are just completing major upgrading of their facilities, inadequate operating funds are forcing these university programs to turn away such students.

- The 20 million step increase in operating support recommended by NSAC--as its highest priority--in the 1983 revision of the long range plan is urgently needed both by the universities and the national laboratories.

- The CEBAF funding profile in FY1989 is 20 million less than optimal and will result in a construction stretch-out, with physics delayed by at least a year from 1993 to 1994.

- The RHIC project--a unique, world class facility--has been reviewed in detail by DOE and judged, "ready for construction". Unless this construction can be initiated in FY1989:

  a) US scientists will lose out to CERN in the competition for access to some of the most important and exciting science in our field.

  b) European and Japanese physicists who were prepared to become major RHIC users (and contributors) will cast their lots with other facilities in Europe and Japan.

  c) The high quality construction staff at Brookhaven will continue to disperse.

FIGURE 27

That's it. Good. The first is the fact that increasingly some of the best graduate students in physics in the entire country have decided they want to come and work in nuclear physics. In my own department at Yale, for example, last year fully 50 percent of all the graduate students in physics decided they wanted to work in nuclear physics. Now the problem that I have, and that I share with a number of the American universities, many of whom like us have just had entirely new facilities installed to give us much greater research capability, is simply that we had inadequate operating funds and we are turning away many of these very highly qualified students who would otherwise join us and do advanced research with us. This, I think, is a loss to the scientific and technical community in this country that we can ill afford.

We have kept detailed statistics over the years on our graduates. We are one of the largest producers of trained people in this field. Forty percent of our students work in industry; 40 percent are in academia; 20 percent work in Government and other areas, and this is a not atypical distribution.

The $20-million step increase that was recommended as the highest priority by NSAC back in 1983 has not appeared. It has not been possible for DOE to respond to that recommendation as yet but it is something that is very much needed, both in universities and in the National Laboratories.

For this year, for example, Mr. Chairman, the best evidence suggests that our facilities will be utilized to 57 percent of their capability, and as I say, we are turning away some very highly-qualified graduate students.

The next point has to do with CEBAF funding. As I have indicated, CEBAF is a truly unique facility. It will give us one in the United States that is not matched anywhere else and it is fortunate that we have put together at CEBAF a truly outstanding management group both in construction and in science, but I have to tell you that generous as the support is for this year, for 1989, the funding profile is some $20 million less than optimal and this will be reflected in at least a year's stretch out in the construction, which will mean that some very exciting scientific work will be stretched out into 1994, starting in 1994 rather than starting in 1993.

And my third point: the RHIC project at Brookhaven is one that has been reviewed in detail by the Department of Energy and was found "ready for construction." There are three points at least I want to make.

First of all, unless we can get an expeditious start on building this unique facility—it too is unique—unless we can build it rapidly, we are going to lose in an international competition with the group at CERN for some of the most exciting physics in the next decade.

Secondly, large groups of European and Japanese physicists have been prepared to commit their research careers and a substantial amount of financial support to working with us at RHIC if we can get a start in Fiscal Year 1989. The problem is that they have been holding fire for several years, waiting for this start, and if we are unable to do that, then they tell us that they will commit to CERN and to other Japanese facilities, and we will have lost the opportunity for this cooperation with outstanding groups of scientists, both in Europe and in Japan as well as their support.

And lastly, of course, any laboratory that is prepared to build a facility like RHIC has a very high-quality construction staff. Brookhaven, in particular, has one left over from the CBA days—the Colliding Beam Accelerator days. That group is dispersing, and it disperses more each year. The longer we wait to start the more difficult it will be to bring together this talented group to do this construction job for us.

So that Mr. Chairman, Ladies and Gentlemen, concludes what I would like to say to you, except that I want to say again how much I have appreciated this opportunity to appear before you. I can report to you that nuclear physics is more exciting, more challenging than it has been for a great many years and that your colleagues, the Department of Energy and the National Science Foundation have built and are building a complement of facilities and a group of scientists in this country of which we in the U.S. can be justly proud. The support continues in Fiscal Year '89 but I brought to your attention three areas where increased support, I believe, would be very highly leveraged in terms of new science and the training of outstanding young people.

And finally, if I had to make a priority decision, I would I'm afraid have to say that the most important of those three problem areas is a start in RHIC in 1989, then at least a beginning of increasing operating funding to increase the utilization of all of the facilities and then to try and bring CEBAF back on schedule.

Thank you, Mr. Chairman.

[The prepared statement of Dr. Bromley and additional materials follow:]

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FRONTIERS OF NUCLEAR PHYSICS

by

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INTRODUCTION

Madam Chairman, and members of the Subcommittee, I welcome this opportunity to appear before you to discuss some of the exciting new developments in nuclear physics as well as some of our plans for the future. In the 77 years since the atomic nucleus was first discovered there have been two particularly exciting and productive periods—one centering on 1932 with the discovery of the neutron—and thus the structure of nuclei—as well as the invention of the Cockcroft-Walton, Van de Graaff and cyclotron accelerators--and one centering on the past year or so.

This is an extremely exciting and challenging time in our science and, as a consequence of enlightened support over the years by the Congress, and by the taxpayers, we, in the US, have in place or under construction, many of the frontier facilities needed to respond to these challenges. And some of the most outstanding of our current graduate students in physics are choosing to join us.

With your permission, Madam Chairman, I should like to submit for the record a much more complete paper entitled, **The Future of Nuclear Physics** that I prepared last year for presentation at a NATO Summer School in Italy, as well as a shorter one entitled, **The Nucleus—Its Impact on Science and Society** prepared for presentation to an American Physical Society sponsored luncheon here in the House Office Building about a year ago. These papers provide a backdrop against which today I should like to focus on some of the more recent discoveries as well as a few problems areas that I should like to bring to your attention.

Although nuclear physics is a science that relies heavily on accelerators and other large instrumentation, let me begin with two examples of recent work that has had no connection with accelerators--demonstrating very effectively that in this science there are still many frontiers, some involving relatively small equipment.

NUCLEAR DOUBLE BETA DECAY

During 1987, Michael Moe and his collaborators, as shown in Figure 1, succeeded—after more than a decade of patient detection development—in observing the rarest physical process yet found, nuclear double beta decay where, in a single process two neutrons change into two protons with the emission of 2 electrons and two electron anti-neutrinos. In the case studied, ^{82}Se decays into ^{82}Kr with a half-life of $1.1 \mathrm{x} 10^{20}$ years—some 10 billion times the age of our universe! Obviously theoretical reproduction of this result poses an enormously stringent test of our knowledge of the structure of these nuclei.

Of even greater interest, but unobserved as yet, would be the same process—but without emission of anti-neutrinos so that, in effect, that emitted in the decay of the first neutron is absorbed in that of the second. If such a process, which Moe and others such as the groups at Irvine, at Berkeley, in the Soviet Union are searching for, were to be observed it would violate the fundamentally observed, but not fully understood law of lepton conservation, could imply the existence of a previously unknown right-handed component in the weak leptonic current, and would require absolutely that the neutrino has a small but non-zero mass. Such a discovery would have a profound impact on all fundamental physics.

NEUTRINOS FROM SUPERNOVA 1987A

My second non-accelerator related discovery also relates to the possible mass of the elusive neutrinos. For the first time in over 400 years a star close enough to the earth for its death to be visible to the naked eye—a blue giant, Sanduleak 69^{o} 202 in the large Magellanic Cloud—underwent the most dramatic and cataclysmic event in the known universe—gravitational collapse. But almost a day before this supernova was first seen, several of the world's large underground detectors used in searching for the still unobserved spontaneous decay of the proton were in operation and, as shown in Figure 2, detected some of the neutrinos from the last stages of the stellar collapse when a neutron star—really a giant nucleus some tens of kilometers in diameter—forms. Not only does this observation prove, once and for all, that neutron stars really exist but also, nuclear physics models, that up until this event were based only on a long chain of assumptions and our knowledge of nuclear phenomena, have been shown to reproduce all the characteristics of the neutrino pulse with remarkable precision. Moreover, just the 20 events observed in all in the proton detectors establish a firm upper limit of 15 eV on the mass of the electron neutrino.

NUCLEAR FACILITIES

Let me turn now to a quick census of the accelerator based programs in US nuclear physics as listed in Figure 3. It is important to emphasize the major change that has taken place in the field in the past two decades; from the 90 university-based, accelerator-based programs that were supported by the DOE and NSF in 1969, only 16 remained in 1987 and, of these, three now supported by NSF are scheduled for shut down. This represents a reduction by a factor of 7 over this period. While some of these universities have remained active in nuclear physics in a user mode, many have dropped from the field and thus no longer train graduate students in this science.

THE NUCLEAR SCIENCE ADVISORY COMMITTEE LONG RANGE PLAN

Obviously, while undergoing such major changes in its internal structure it was essential that these changes be carried out in a systematic and careful fashion in order to retain the vitality and health of the field while allowing it to adjust to take advantages of new challenges and opportunities.

To that end, the Nuclear Science Advisory Committee (NSAC)—reporting jointly to DOE and to NSF—was asked, in 1979, to prepare, after consultation with the research community involved, a long range plan for the orderly development of US nuclear science. This 1979 plan was accepted by DOE and NSF and has served as the basis for subsequent activity as listed in Figure 4. With a significant fraction of the 1979 recommendations in place, in 1983 NSAC was asked to revisit the long range plan and, after discussions with representatives of the national community, NSAC reaffirmed the outstanding 1979 recommendations and added to them as shown in this Figure.

The existence of this long range plan and adherence to it both by the federal agencies and by the nuclear physics community has provided a vitally important stability and basis for planning during a period of rapid change.

PROGRAMS WITH LOWER ENERGY POSITIVE ION ACCELERATORS

In the past few years, the availability of high precision, low energy nuclear accelerators, of new much more powerful detector systems, and of computer-based data acquisition and analysis systems, has resulted in a renaissance in nuclear spectroscopy comparable to that brought about in atomic physics by the advent of the laser.

For the first time, these developments have made hot, high-spin nuclei accessible to study. In a single 1986 measurement at the Daresbury Laboratory in England—one now duplicated and extended in laboratories worldwide—it was found possible to **double** the angular momentum of quantum states accessible to precision study—from 30ħ to 60ħ.

HIGH SPIN, HOT NUCLEI

In Figure 5, I show a plot of nuclear spin against neutron number in the much studied dysprosium isotopes ranging from the magic neutron number 82 to 94. The shaded region was that accessible to precision study prior to 1986; now the entire figure is open to such study.

At low spin it has long been recognized that at N=82 the nucleus has a stable spherical shape and that adding a few valence neutrons makes it rather soft and susceptible to vibration, about the spherical equilibrium, from football to doorknob shapes. As more and more neutrons are added they eventually stabilize the nucleus into a stable football shape. But these are all cold nuclei, very close to their quantum ground states.

As the spin is increased, and as the nuclei become hotter, the added angular momentum is accommodated both by spinning the deformed core and by systematically aligning the orbits of the valence neutrons and protons to add their angular momenta to that of the core; signatures for such alignment are now well known.

Recent calculations, in which a very general Landau theory based on quantum statistics has been applied to these hot nuclei, with temperatures in the range from 1 to 3 MeV (12 to 36 billion degrees Kelvin) have made the surprising prediction that phase transitions analogous to the vastly lower temperature ones where water freezes or boils are anticipated but in the nuclear case the transition is one between different shapes—spherical, oblate, prolate and triaxial. Very preliminary data on gamma radiation from giant nuclear resonances (where all the neutrons oscillate against all the protons) built on excited states of nuclei in the dysprosium region may already have identified the first of these phase transitions.

Measurements at Daresbury have shown conclusively that in ^{152}Dy (N=86) at angular momenta near 60ħ this nucleus is **superdeformed** with an axis ratio of 2:1 confirming at least one of the earlier guesses that led to the construction of this Figure.

The opportunity to examine phase transitions in the nuclear quantum system opens the way to entirely new physics, and to the understanding of a unique many-body quantum system with enough components to yield interesting and complex phenomena while at the same time a small enough number of components to make a detailed microscopic understanding of these phenomena a reasonable expectation. Such understanding will have a major impact on many areas of science far outside nuclear physics.

As shown in Figure 6, our knowledge of the structure of these hot nuclei is developing rapidly so that, it is now possible to calculate what the potential energy surface that determines the nuclear shape and behavior might look like at very high spin—here 80ħ; the minima that correspond to the normal deformed low-spin nuclei, to the recently discovered superdeformed ones, and to the, as yet undiscovered, **hyperdeformed** ones having a stable dumbbell shape are clearly evident.

Laboratories around the world are mounting major efforts to find and study such super and hyperdeformed nuclei and the phase transitions that are predicted to separate some, or all, of them.

SYMMETRIES IN NUCLEI

Much of the progress that has been made over ~~the years~~ toward fundamental understanding of nature has reflected recognition of the underlying symmetries that govern observed behavior. This has been particularly true in nuclear physics in recent years. Whereas formerly we dealt with a great many models of nuclei—shell models, liquid drop models, collective and cluster models of varying complexity—recognition that all could be placed on a common footing based on a group theoretic ordering of pairs of neutrons and protons—analogous to the electron Cooper pairs that play crucial roles in the theories of superfluidity and of low temperature superconductivity—has resulted in major progress in correlating and understanding, on a more fundamental basis, the flood of new information about nuclear structure that is resulting from the renaissance in nuclear spectroscopy noted earlier. For the first time we have a unified picture of how all nuclei are structured.

More recently tantalizing evidence has been reported suggesting that the same symmetry-based approach may lead to a corresponding unification of our models for nuclear dynamics and interactions, ranging from elastic and inelastic scattering through much more complex rearrangement interactions. Figure 7, shows the remarkable fits to four quite distinct reaction channel data obtained simultaneously, and without relative normalization, using this new symmetry based approach. Equivalently tantalizing results have been obtained in applying this same approach to particle physics data on the scattering and interactions of nucleons instead of nuclei.

What are needed to test and understanding the limits of this symmetry-based approach are many more precise interaction cross sections, measured as functions of both energy and angle for representative nuclear systems.

To all the above mentioned frontier areas—and a great many more that space does not permit including—the modern low energy precision accelerators are uniquely suited.

REPRESENTATIVE LOW ENERGY ACCELERATOR FACILITIES

Figure 8 shows a stage in the recent upgrading of our facilities at Yale. The smaller submarine-like tank on the right is that which contained the electrostatic structure of the first of the MP class of Van de Graaff accelerators that, when it was dedicated in 1966, was the world's most powerful electrostatic machine operating up to 10.5 million volts. The larger (3 times the volume) tank being moved into the laboratory in this photograph is that of the first of the ESTU class which has already been operated to voltages above 22.5 million. A better impression of the true size of the electrostatic structure inside this tank can be gained from Figure 9—a photograph taken from the floor of the tank directly under the central high voltage terminal looking toward the tank end.

Figure 10 illustrates the superconducting linear postaccelerator recently added to a 9 million volt FN class tandem accelerator at the University of Washington in Seattle. This facility is complementary to that at Yale in that it is optimized for light ion work whereas ours covers a much broader range of projectiles.

Figure 11 shows the superconducting linear postaccelerator recently installed with another FN class tandem accelerator as the ATLAS facility at the Argonne National

Laboratory. An electron cyclotron resonance (ECR) source and linear pre-injector is currently being added to the ATLAS facility to expand the range of its possible projectiles all the way to uranium.

Figure 12 shows the K800 second cyclotron at the National Superconducting Cyclotron Laboratory at the Michigan State University with its builders. This new facility is supported by the NSF while all the others illustrated in this paper are DOE supported.

It is essential that I emphasize, before moving on to frontiers of our field that center on much larger facilities, that these smaller university and National Laboratory facilities, because of their precision and flexibility, remain very much on the intellectual frontiers of nuclear physics. They are complementary to the larger facilities and progress in our science comes from synthesis of the observations made with many different facilities; without the results obtained with the smaller machines it would be quite impossible to understand those obtained with the larger ones. And the university-based facilities, in particular, play a critical role in the attraction and training of each new generation of nuclear scientists.

ELECTRONS AS NUCLEAR PROBES

It is important to emphasize that all of the studies to which I have referred thus far primarily involve the nuclear surface, its shape, and the valence nucleons moving in it. To see deep inside the nucleus we require a probe that illuminates the entire nuclear volume and is not stopped in the surface; such a probe is a high energy electron. It has the additional advantage that the electromagnetic force whereby it interacts with the nucleus is the most completely understood of the forces of nature and thus makes extraction of the underlying physics from experimental measurements much more direct and simple.

As emphasized in the 1979 NSAC long range plan (Figure 4) and in the reports of all subsequent NSAC subcommittees and panels, the US nuclear physics community in 1979 had recognized that its highest priority for major new facility construction was for a high energy, high duty-cycle electron facility. Initial discussion focussed on an energy of 2 GeV but as plans developed and as the physics was examined in greater detail this maximum energy moved up to at least 4 GeV—the initial specifications for the Continuous Electron Beam Accelerator Facility (CEBAF), approved by DOE in FY1987 and now under construction at Newport News.

Figure 13 illustrates, in schematic fashion, what is expected in the interaction of high energy electrons with a typical nucleus and with a nucleon. In the case of the nucleon, here represented by the proton, there is first elastic scattering of the electron off the usual proton; as the energy of the electron is increased some of this energy of relative motion can appear as internal excitation of the proton—in inelastic events leaving the proton in its excited quantum states, the Δ and the higher N^* resonances; as the energy is increased further, the electrons begin to interact individually with the constituent quarks and gluons in the proton in deep inelastic scattering events such as those studied in recent years at the 30 GeV SLAC linear electron accelerator at Stanford University.

In the case of scattering from a nucleus, again both elastic and inelastic scattering involving the ground and low-lying excited quantum states of the nucleus appear, including states deep in the nuclear interior; at higher energies come the giant resonances wherein the neutrons and protons act collectively as fluids oscillating against one another; at still higher energies the individual neutrons and protons become excited to their Δ and N* isobars; and at still higher energies, in the range from about 2 to 6 GeV, the nucleons begin to melt—much as glass would melt rather than water in that there is no sharp phase transition or melting temperature. Current evidence suggests that the quarks and gluons in the nucleons begin to be deconfined—begin to be free to move throughout the entire nuclear rather than the nucleon volume—in the first stages of development of a quark-gluon plasma—an entirely new fifth state of matter.

It is this transition between **hadronic** matter, where protons, neutrons and pions are the dominant participants, and **quark** matter, where quarks and gluons play the dominant roles, that is of particular interest here. It is recognized that the situation becomes much simpler at much higher energies, greater than 25 GeV say, where the quark matter is fully developed and where quantum chromodynamics—the theory of the strong nuclear interaction—can be applied in its perturbative limit. At the lower CEBAF energies, up to 4 to 6 GeV, the complexity resulting from the fact that the quark gluon plasma is **not** fully developed is balanced by the opportunity that this energy range provides to trace out the transition from ordinary hadronic matter to the entirely new quark matter, even though the phenomena involved will require the full power of quantum chromodynamics, without any perturbative simplification, for their understanding.

Figure 14 is an aerial view of the CEBAF site, with the facility as it will be when construction is completed superposed in white upon it. Clearly shown here are the locations of the two parallel 0.5 GeV superconducting linear accelerators and the semi-circular magnetic arcs that allows the electron beam to be recirculated through them 4 times to reach the original design energy of 4 GeV before being directed to one of the three circular target areas shown with their heavy earth shielding berms and service buildings at the lower left of this photograph. The large central white building is that which formerly housed the NASA Space Radiation Effects Laboratory (SREL) cyclotron and which now provides development space for the CEBAF superconducting RF cavities and other critical hardware.

Figure 15 provides a measure of the uniqueness of this new CEBAF facility, here shown identified with its parent's [Southeastern University Research Association (SURA)] acronym. It bears noting that this is a logarithmic plot on both axes; currently the MIT-Bates facility is being modified to give essentially 100% duty factor at just under 1 GeV.

Figure 16 provides a convenient summary of the scientific motivation for the CEBAF facility. Construction is now fully underway with first experiments scheduled for 1994. This facility has provided a new focus for world-class frontier experimental nuclear physics for the several tens of southeastern universities affiliated with SURA, and for the 50 universities nation-wide that have already submitted letters of intent to CEBAF. As emphasized in Figure 15, CEBAF will provide US nuclear physics with a facility unmatched anywhere in the world.

THE NUCLEAR EQUATION OF STATE

One of the central open questions in nuclear and astrophysics and in cosmology is that of how nuclear matter—the matter comprising over 98% of our physical universe—behaves when it is exposed to extreme conditions. Figure 17 summarizes present speculations on this matter—on the nuclear equation of state.

Here the equation of state is plotted as temperature against density. Normal nuclei would be found on this plot at the normal nuclear density ρ_{nm} and at effectively zero temperature. As the temperature—or the density—is raised the nucleons in these nuclei come into evermore intimate contact and eventually it is to be expected that they lose their identity and again melt into a quark-gluon plasma. Our best current calculations suggest that a temperature of about 200 MeV (2.4 trillion degrees K) would suffice to cause this transition at low density or a density some 5 to 10 times normal would suffice at low temperatures.

If we were dealing with an infinite volume of nuclear matter, the transition would be expected to be perfectly sharp but since we inevitably deal with nuclei of finite volume it is smeared out into the band shown in this Figure.

We know that this figure has already been traversed in at least two of its limits. In the early universe, as the temperature dropped with expansion, hadronic matter—familiar in the universe today—condensed out of the primordial quark-gluon plasma when its temperatures fell to about 200 MeV, several hundred milliseconds after the initial Bang. And in the formation of neutron stars, now verified in Supernova 1987A, and particularly in heavier stars that proceed to the black hole stage, at relatively low temperature, gravitational contraction increases the density of the stellar matter beyond the critical transition density so that hadronic matter is crushed, inexorably, into quark matter—and beyond.

The question at issue, however, is whether we can cross this transition from hadronic to quark matter under controlled conditions in the laboratory—whether we can recreate the conditions, if only for the brief instants required for our measurements, that existed within a second of Creation or that exist in the final seconds in the life of a dying star.

There are other tantalizing possibilities indicated in this figure. At densities between about twice normal and the transition density, it had long been thought that it might be possible to obtain a pion condensate—a fascinating state of matter wherein the neutrons and protons systematically give up much of their mass to form a cloud of pions and in which the pion wave functions would be expected to display the same kind of coherence found for the photons in a laser. Repeated experiments have found no evidence for this condensation however, and the concensus is growing that it does not exist in nature; at the same time, however, quantum chromodynamics points to a growing probability that kaon (the lightest **strange** meson) condensates **may** exist.

Experiments at the Berkeley BEVALAC have shown, conclusively, that since the velocities of nuclear projectiles at relativistic energies exceed the velocity of sound in nuclear matter, nuclear collisions at these energies give rise to shock waves—entirely analogous to those responsible for sonic booms in the atmosphere. These shock waves, in turn, produce both condensation to much higher than normal density in nuclear matter **and** rare-factions to much less than normal densities. In these latter regions it would be anticipated that there is at least the possibility of finding a second phase transition into the liquid and gaseous phases of hadronic matter. All such phenomena would provide vital new insight into how nuclear matter behaves under unusual and extreme conditions.

RELATIVISTIC NUCLEAR COLLISIONS

The recent Berkeley data demonstrated that densities much higher than normal can be produced in high energy collisions between massive nuclei. But the open question has been whether such collisions can produce a pure quark-gluon plasma given adequately high energies.

Figure 18 is a highly schematic representation of the collision with a uranium nucleus at rest of an accelerated uranium nucleus, entering from the left at relativistic energy such that the relativistic contraction in the direction of motion has converted it into a disc as viewed from the laboratory reference frame. In the center panel it is already incident upon the target uranium nucleus and, in the lower panel, it has passed completely through the target nucleus.

As these nuclei pass through one another both are raised to enormous temperatures and after the collision there remains a rapidly separating target region and a different projectile region in space each filled with hadronic and quark products of this encounter. In between, just after the collision, as shown here, however, there is an exceedingly hot—so-called **fire tube**—linking the target and projectile regions where it is believed that a pure quark-gluon plasma should exist, uncontaminated by any of the target or projectile hadronic fragments.

EXPERIMENTS AT CERN AND AT THE BROOKHAVEN AGS

During the past year, it has been possible, both at Brookhaven and at CERN, to at least begin to explore this new domain which brings particle, nuclear and astrophysics together with cosmology and indeed many aspects of condensed matter science as well.

Figure 19 provides a summary of some of the most important results—results which have far exceeded the expectations of even the most optimistic researchers in what were intended as very preliminary exploratory studies.

At Brookhaven, beams of ^{16}O, ^{28}Si, and ^{32}S, accelerated in an MP tandem accelerator (See Figure 8) were carried, in a 1000 meter transfer line, to the venerable Alternating Gradient Synchrotron (AGS) where they were accelerated to energies of 15 GeV/nucleon. At these energies, to everyone's surprise and gratification, these projectile nuclei were completely stopped in target nuclei from copper to gold; densities some 4 times normal were deduced from the measurements; and kaon to pion ratios greater than 20% higher than those associated with nucleon-nucleon collisions at corresponding energies were found; this latter is important evidence that the heavy nuclear collisions cannot be understood as simple ordered collisions of the nucleons in the projectile with those in the target and evidence that collective phenomena, involving many nucleons simultaneously, are important.

This highlights one of the major differences in the goals of frontier particle and nuclear physics. In the former, the goal is that of delivering evermore energy to ever smaller volumes in the hope that some, at least, of it (E*) will materialize to yield previously unobserved new particles of mass $m = E^*/c^2$. In the latter, the goal is that of delivering evermore energy to relatively large volumes (e.g. those of heavy nuclei) containing many nucleons and thus susceptible to the appearance of collective phenomena.

At CERN, using the PS and SPS accelerators, it has been possible to produce ^{16}O and ^{32}S beams at energies up to 200 GeV/nucleon. At these energies it is found that the target nuclei are **partially** transparent (See Figure 18) and that energy densities 7 times normal are reached in the collisions. Moreover, since a very large number of charged particles, pions, protons etc. emerges from each collision, it is possible to use an intensity interferometric technique to determine the size of the source from which these particles emerge. This is a variant of the Hanbury-Brown and Twiss technique, originally devised to measure the diameter of the star Sirius.

Figure 20 is a computer reconstruction of the products of the collision of a 200 GeV/nucleon ^{16}O projectile with a gold nucleus as photographed in a streamer chamber at CERN, illustrating this high multiplicity and the experimental difficulties involved in extracting the underlying physics from such data.

That the CERN measurements mark an approach to the quark-gluon plasma is evidenced by the fact that a clear J/ψ resonance is observed—providing a signature for the production of heavy charmed quarks in the collision—but that its intensity is 65% weaker in central than in the peripheral ones as would be expected as a consequence of color screening in a developing quark-gluon plasma.

THE RELATIVISTIC HEAVY ION COLLIDER

Although tantalizing and important, what all the high-energy, heavy ion data-to-date emphasize is that we need higher energies and heavier projectiles if we are to hope to cross the frontier into the quark matter domain in clear fashion and be able to study the characteristics of this new state of matter unambiguously and with precision.

It bears emphasis that since both the AGS and CERN programs necessarily involve collisions with targets at rest, the energies available in the center-of-mass reference frames—the useful energies—are 5 and 20 GeV/nucleon, respectively and are very much less than those produced by the accelerators in the laboratory frame of reference.

An obvious approach to remedying this situation is to turn to the collider concept used so successfully in particle physics. With the termination of the Colliding Beam Accelerator (CBA) program at Brookhaven in 1983, fully one-half of the cost of a collider system for heavy ions had already been expended on the construction of the 3.8 km ring, the refrigeration for the superconducting magnets, power supplies, offices and laboratory buildings, site preparation and the like. This represented an opportunity for the design of a singularly cost-effective heavy ion collider to which Brookhaven and the US nuclear physics community responded enthusiastically. In its 1983 revision of the long range plan for US nuclear physics, noting that CEBAF was well underway, NSAC gave its highest priority for new construction to the relativistic heavy ion collider (RHIC) at Brookhaven with a target date of fiscal year 1988. Although the project has passed all relevant DOE reviews and is now officially judged "ready for construction", construction funding for it was not made available in FY1988 nor has it been included in the Presidential request submitted to Congress for FY1989.

Because of the dimensions of the existing CBA ring, it has been possible to develop a very cost-effective RHIC design for a 100 GeV/nucleon on 100 GeV/nucleon collider—with 200 GeV/nucleon in the center-of-mass and thus a factor of 10 higher energy than can be attained at CERN with existing accelerators. As shown in Figure 19, the data obtained during the past year at AGS and at CERN make it reasonable to expect energy densities 20 to 70 times normal at RHIC energies; densities 5 to 10 times normal; fully developed quark-gluon plasmas; and forays into an entirely new domain of nuclear and particle physics—a domain with very close ties to both astrophysics and cosmology. This is an exciting and challenging prospect.

Figure 21 is a current aerial photograph of the Brookhaven site showing the tandem accelerator injector at the lower right, the transfer line to the AGS in the center of the photograph and the CBA ring and facilities to be used in RHIC in the background. Also indicated in this figure is the booster, now under construction, that will raise the AGS intensity for protons—thus kaons—by a factor of four and also extend the range of heavy ion projectiles that can be accelerated in the AGS—and thus transferred to RHIC from 32S to 197Au.

Figure 22 shows the relative characteristics of present and planned heavy ion accelerators, worldwide, plotting equivalent fixed-target energy per nucleon against projectile mass. As indicated here, by using RHIC in a fixed-target mode, as well as in the collider mode, it becomes possible to span the entire equivalent fixed-target energy range to some 30 TeV/nucleon. As noted previously, the Booster at BNL will extend the range of available heavy ion projectiles from ^{32}S to ^{197}Au for both AGS and RHIC. Reflecting the interest and excitement generated at CERN by the preliminary relativistic heavy ion experiments of this past year, a formal proposal is being presented to CERN management later this year, that would result in the available projectile range at CERN also being extended from ^{32}S to ^{208}Pb. CERN representatives currently estimate a 95% success probability for this proposal.

It bears emphasis that although the energy frontier in heavy ion physics is moving upward rapidly, there remains a very open frontier in the intermediate energy range that has been largely leapfrogged in the move to relativistic energies. The richness of the phenomena in this intermediate energy range was emphasized recently by the Vogt subcommittee of NSAC and is demonstrated by the major construction program at the GSI Laboratory in Darmstadt and by the proposal that has been developed at Berkeley for the upgrading of the BEVALAC. Both of these latter programs are directed toward the production of high luminosity beams of all heavy ions in the energy range up to about 5 GeV/nucleon.

Figure 23 summarizes some of the scientific motivation for the RHIC project.

THE HIGH INTENSITY FRONTIER

Although my focus thus far has been mostly on higher-energy frontiers, there is a complementary high-intensity frontier that is of growing importance and interest. Its primary manifestation has been in the area of so-called kaon factories—high intensity proton accelerators capable of producing high intensity secondary kaon beams that will allow whole new generations of study on hypernuclei—nuclei wherein one or more of the nucleons have been converted into lamda or sigma hyperons—and where these hyperons can, in the absence of Paul Principle restrictions, enter already full shell model orbits and where the strangeness quantum number enters the nuclear domain in a major way. Beyond such studies, these kaon factories give access to many of the rare decay modes of the kaon itself—at levels that are entirely impossible at existing facilities—and thus permit testing of the Standard Model of particle physics in entirely new ways.

Inelastic scattering of kaons off nuclei is very much complementary to such scattering of either electrons or muons in that only the former are sensitive to the different quark flavors present and only the former also can provide new information on the separate behavior of the valence and sea quarks in the nucleus beyond that provided in the now familiar EMC effect observed—but not fully understood—in the inelastic scattering of electrons and muons.

Figure 24 is a layout drawing of the Advanced Hadron Facility (AHF) designed at Los Alamos as typical of this new class of kaon factories. It would take protons from the existing LAMPF proton linac and in three stages, as indicated, raise the energy to 60 GeV. A very active group at the TRIUMF Laboratory in Vancouver, Canada is currently seeking international participation in a 30 GeV facility that would be injected by the TRIUMF cyclotron and at the KEK Laboratory in Japan the decision has been made to convert the existing TRISTAN proton synchrotron into what might be termed a mini-kaon factory.

THE PEOPLE OF NUCLEAR PHYSICS

Having touched both on some of the scientific frontiers of nuclear physics and the facilities required to reach them, I would be remiss were I not to at least mention the people of nuclear physics. As noted in Figure 25, training in nuclear physics prepares students for a wide range of career opportunities. Our own Laboratory at Yale, as one of the largest producers of such personnel at the doctoral level, has maintained detailed records over the past several decades; we find that about 40% of our students stay in academic careers, 40% join industrial organizations while the remaining 20% are in governmental and other organizations.

Our success with nuclear physics as a training field reflects the fact that our activities are such that we can still allow a student, occasionally, to make mistakes—and learn from them—and are such that an individual graduate student can still carry the dominant responsibility for all aspects of an investigation on the intellectual frontiers. But equally important, in order to make progress on these frontiers, that student not only must develop expertise in a great many related areas of science and technology but also must adopt a **systems** approach and must be able to enlist the assistance and cooperation of other graduate students, faculty and support personnel.

Such experience in attacking rather large and unstructured problems provides students with a level of self-confidence as well as technical competence that serves them well in their later careers and that makes them valued partners in the search for solutions to some of the major problems facing US industry and society today.

As an academic nuclear physicist I would feel that I had failed miserably in my educational responsibilities if all my graduate students wanted to stay in nuclear physics throughout their subsequent careers.

It bears emphasis that, many of the leading industrial countries, including those listed in Figure 25, have paid particular attention to nuclear physics, focussing their resources on it to a substantially greater extent than do we in the US, and in doing so they have frequently noted that they were making this decision as an effective approach to strengthening and extending their national technological bases.

Although, I shall not have the time today to discuss any of the many applications of nuclear physics, I would like to quote a striking statistic used by Dr. Alvin Trivelpiece, then Director of the Office of Energy Research in the US Department of Energy in a recent presentation to President Reagan. He said, **"one-third of our current Gross National Product can be traced to better knowledge of the atom".**

The nation's investment in both basic and applied nuclear research, over the years, has paid handsome dividends affecting all aspects of our lives—in national security, in energy, in technology and in medicine. I am entirely confident that support of such research remains an excellent investment.

THE FY1989 DOE BUDGET

In your letter inviting me to appear before you this morning, Madam Chairman, you have specifically requested that I comment on the DOE budget for FY1989. As shown in Figure 26, the Presidential request for FY1989 represents a 7.75% increase over the budget for FY1988—but 4.5% of that increase is committed to CEBAF construction. By any reasonable measure, in a year when the major budget focus is on deficit reduction and when a great many areas of federal support are experiencing substantial cuts, this budget request must be recognized as a generous response to the opportunities and challenges that the field of nuclear physics has brought forward.

There are, however, Madam Chairman and Members of the Subcommittee, three problem areas that I must bring to your attention. All three reflect departures from the NSAC long range plan (See Figure 4) and are listed in Figure 27. They are the following:

- The $20 million step increase in operating funding that was the highest priority in the 1983 NSAC review of its long range plan has not become available. The problem is serious in both universities and national laboratories whose facilities are, this year, expected to operate at only 57% of capacity. It is particularly serious in a number of the DOE supported universities, where major upgrading of their facilities have just been completed, and where, over the past several years, operating budgets have simply kept pace with inflation. The incremental operating funding essential to utilization of the increased sophistication and research potential of these new facilities has simply not been available. Most serious of all, however, is the fact that at a time when the number of university-based nuclear physics programs is at an all-time low but when increasing numbers of the most able graduate students are choosing to work in nuclear physics, we are being forced to turn them away for lack of the necessary operating support. Such students are vitally important to our national future.

  Incremental operating funding is urgently needed across the field. The 1983 NSAC recommendation of $20 million is still a conservative one—divided roughly evenly between the universities and the National Laboratories.

- CEBAF construction is proceeding in excellent fashion and an outstanding scientific and technological team has been assembled. The requested construction funding for CEBAF in FY1989 of $44.5 million, however, is $20 million less than would be optimal for the project and will result in a construction stretch-out with the vital new physics that CEBAF will make available then being delayed by at least a year, from 1993 to 1994.

- The RHIC project at Brookhaven, is fully ready for construction. Unless construction can be initiated in FY1989 there are several unfortunate consequences—all with serious long term effects.

  a) The large groups of European and Japanese physicists who have repeatedly indicated their desire to utilize the unique RHIC research capabilities—and their ability to bring substantial funding in the form of detector systems and support personnel that would strengthen the entire RHIC enterprise—have been waiting for a definite US commitment to proceed with the RHIC project. If we are unable to initiate construction this year we are told that the majority of these foreign physicists will make firm commitments to CERN and to other facilities and will therefore be unavailable to participate in the RHIC program. This will represent a major loss--both scientifically and economically.

b) When the CBA project was terminated, Brookhaven had a very highly skilled engineering and technical staff fully engaged in state-of-the-art accelerator construction. With the initiation of the RHIC project--and work on SSC projects--Brookhaven has been able to hold many of the key accelerator science and engineering personnel—although the total number of such personnel at Brookhaven has decreased to about one-quarter of what was available at the end of the CBA project.

The remaining group is uniquely qualified to build RHIC but in the absence of a FY1989 construction start the dispersal of these key people will continue and once dispersed they can never be reassembled.

c) The results of the past year, both from AGS and from CERN, have made relativistic heavy ion science clearly one of the most exciting frontiers of nuclear physics and have attracted major interest on the part of the world's particle physics community as well. If we can initiate RHIC construction in FY1989 we can maintain our leadership in this frontier field. If not, given the high degree of enthusiasm and support evident at CERN, we can very well lose this leadership and find that over the next decade the lion's share of the major new discoveries concerning the fundamental structure of matter will be made outside of the United States.

CONCLUSION

Madam Chairman, I have much appreciated this opportunity to appear before you and the Subcommittee. I can report to you, in conclusion, that nuclear physics has never been more exciting or more challenging and that, over the years, you and your colleagues in the Congress, working through the National Science Foundation and the Department of Energy, have built--and are building—a complement of facilities and have trained a group of scientists of which the US can be justly proud. This support continues in FY1989--but I have brought to your attention three areas in which incremental support would be very highly leveraged in terms of important new science and the training of an increased number of our most able young people.

NUCLEAR DOUBLE BETA DECAY

- **Observed first in 1987 by Elliott, Hahn and Moe at the University of California, Irvine.**

- **The rarest process, by a large margin, ever observed in a laboratory.**

- **The two-neutrino mode:**

  $${}^{82}\mathrm{Se} \longrightarrow {}^{82}\mathrm{Kr} + 2e^- + 2\bar{\nu}$$

  Halflife: $(1.1 {}^{+0.8}_{-0.3}) \times 10^{20}$ years

  Physical Review Letters 59 2020 (1987)

- The zero-neutrino mode:

  $${}^{82}\mathrm{Se} \longrightarrow {}^{82}\mathrm{Kr} + 2e$$

  not yet observed

  $${}^{76}\mathrm{Ge} \longrightarrow {}^{76}\mathrm{Se} + 2e$$

  Half life$>6 \times 10^{23}$years

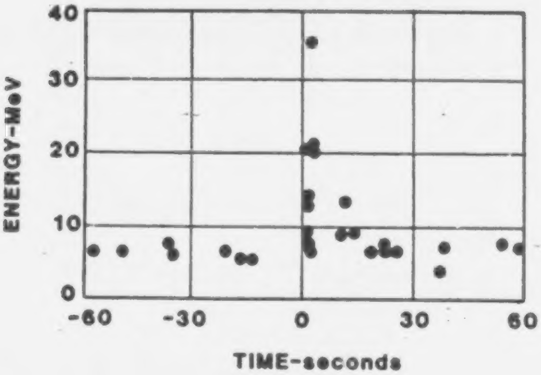
  University of California-Santa Barbara

  Lawrence Berkeley Laboratory - unpublished.

Figure 1

NEUTRINOS FROM SUPERNOVA 1987A

Data from Tokyo-Pennsylvania Collaboration Kamiokande Detector



- Supernova emitted 10^{57} neutrinos in a few seconds -10 times the total number of neutrons and protons in the Sun
- Of these, about 10^{16} passed through the detector and 12 were detected
- Provides first experimental proof of stellar collapse
- Pulse shape remarkably well reproduced by Bethe-Brown theoretical model based on nuclear phenomena
- Pulse duration sets upper limit of 15 eV on the neutrino mass.

Figure 2

US NUCLEAR PHYSICS FACILITIES

1969: ***90 university based, accelerator based programs supported by NSF and AEC***

1987: ***5 university based accelerator based progerams supported by DOE and 11 by NSF***

1987: EXISTING FACILITIES

Large tandem Van de Graeffs	9
Cyclotrons	5
Electron linacs	3
Neutron facilities	4
Proton linacs	1
Total	22

FUTURE FACILITIES

CEBAF (under construction)	1
RHIC (proposed)	1
LAMPF II (proposed)	1
OTHERS	?

Figure 3

THE NUCLEAR SCIENCE ADVISORY COMMITTEE LONG RANGE PLAN FOR US NUCLEAR SCIENCE

AUGUST - 1979 - RECOMMENDATIONS

FY 80	- BEVALAC upgrade to uranium	Completed
	- National Superconducting Cyclotron, Phase II	Completed
	- BATES Energy Doubler	Under Construction
	- Stonybrook Postaccelerator	Completed
FY 81	- ATLAS accelerator Argonne National Laboratory	Completed
FY 82	- Light ion accelerator upgrade (University of Washington-Seattle)	Completed
	- Medium energy CW electron facility (Illinois)	Cancelled
FY 83	- Heavy ion accelerator upgrade (Yale University)	Completed
FY 84	- Nuclear theory computer	Cancelled
FY 85	- High energy light ion upgrade (Indiana University)	Competed
	- High energy CW electron accelerator (CEBAF)	Under Construction

DECEMBER - 1983 - RECOMMENDATIONS

FY 85	- 20M increase in operating funding for existing facilities	Not yet approved
FY 88	- Relativistic Heavy Ion Collider (RHIC - Brookhaven)	Ready for construction

MARCH - 1988 - PROJECTS UNDER DISCUSSION

LAMPF II
(Los Alamos Scientific Laboratory)

BEVALAC UPGRADE
(Lawrence Berkeley Laboratory)

HOLLIFIELD II
(Oak Ridge National Laboratory)

Figure 4

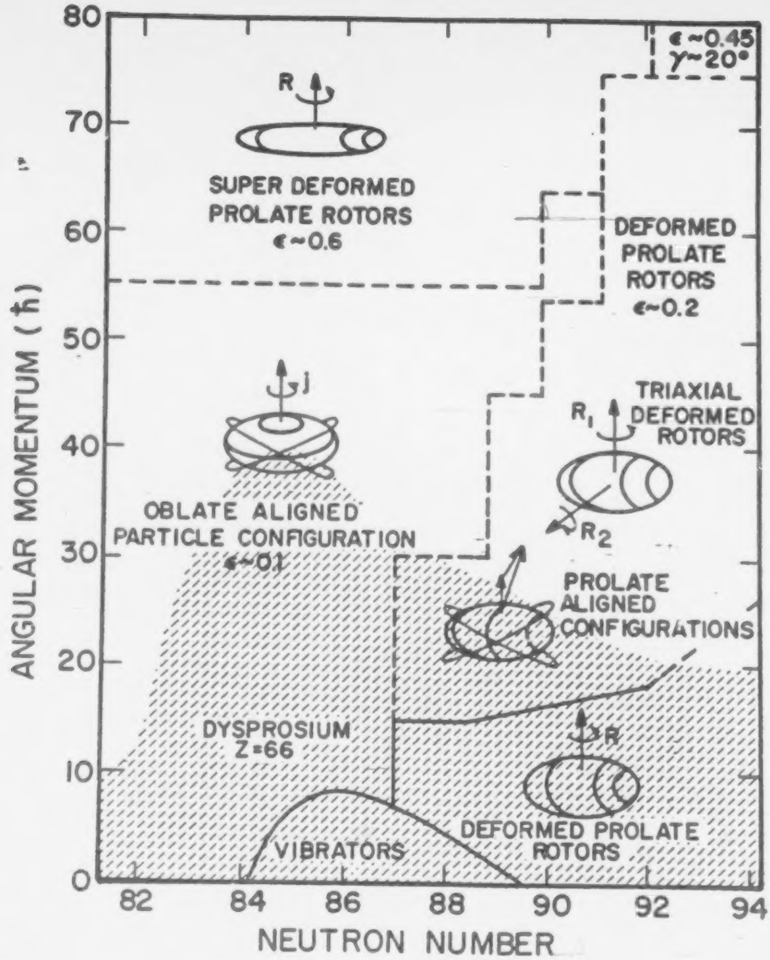

ANGULAR MOMENTUM (ħ)
80
70
60
50
40
30
20
10
0
NEUTRON NUMBER
82
84
86
88
90
92
94
ε~0.45
γ~20°
R
SUPER DEFORMED
PROLATE ROTORS
ε~0.6
DEFORMED
PROLATE
ROTORS
ε~0.2
j
OBLATE ALIGNED
PARTICLE CONFIGURATION
ε~0.1
TRIAXIAL
DEFORMED
ROTORS
R1
R2
PROLATE
ALIGNED
CONFIGURATIONS
DYSPROSIUM
Z=66
R
VIBRATORS
DEFORMED PROLATE
ROTORS

Figure 5

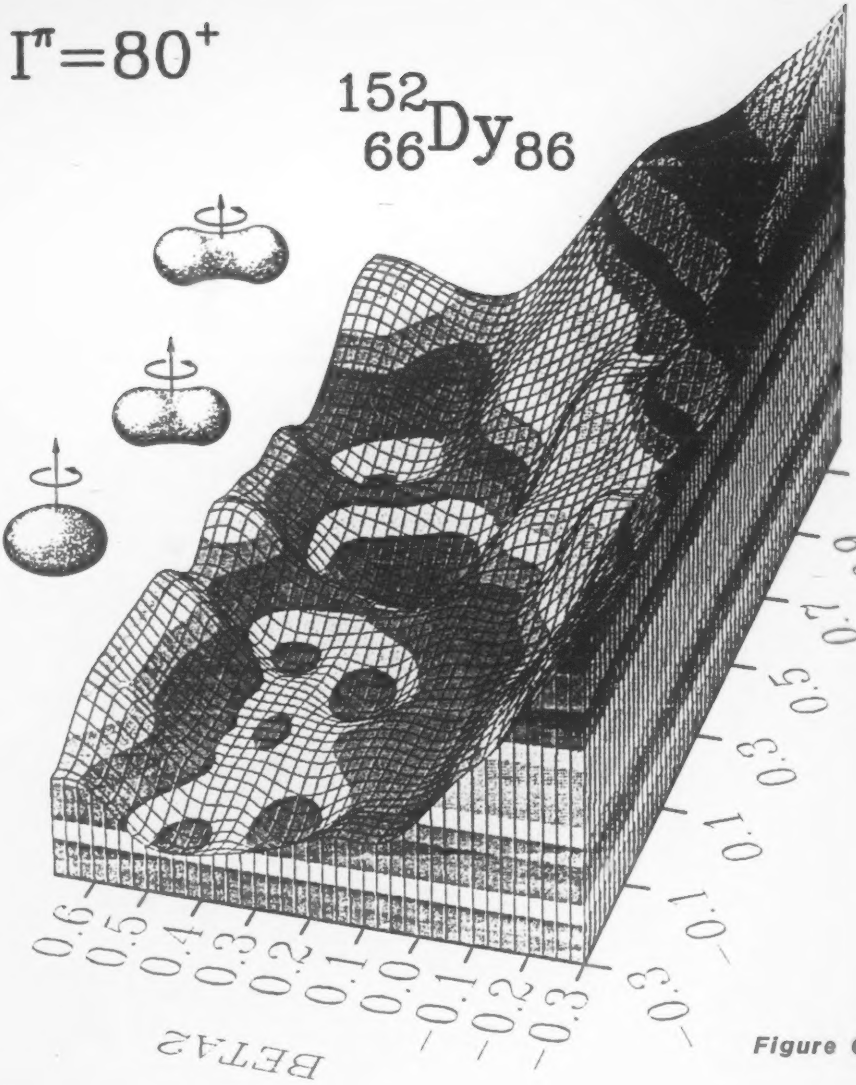

$I^\pi=80^+$
$^{152}_{66}Dy_{86}$
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
BETA2
-0.3
-0.1
0.1
0.3
0.5
0.7
0.9
1.1

Figure 6

$^{16}O + ^{24}Mg$ INTERACTIONS

EXPERIMENTAL DATA: PAUL et al., Argonne
CALCULATIONS: Alhassid, Iachello and Shao, Yale.

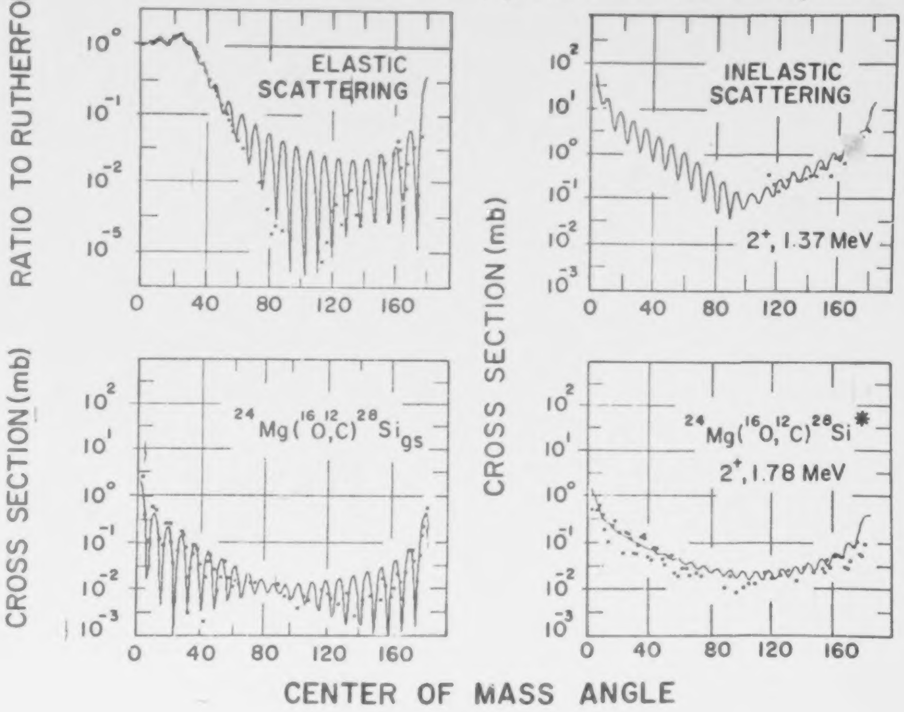


Figure 7

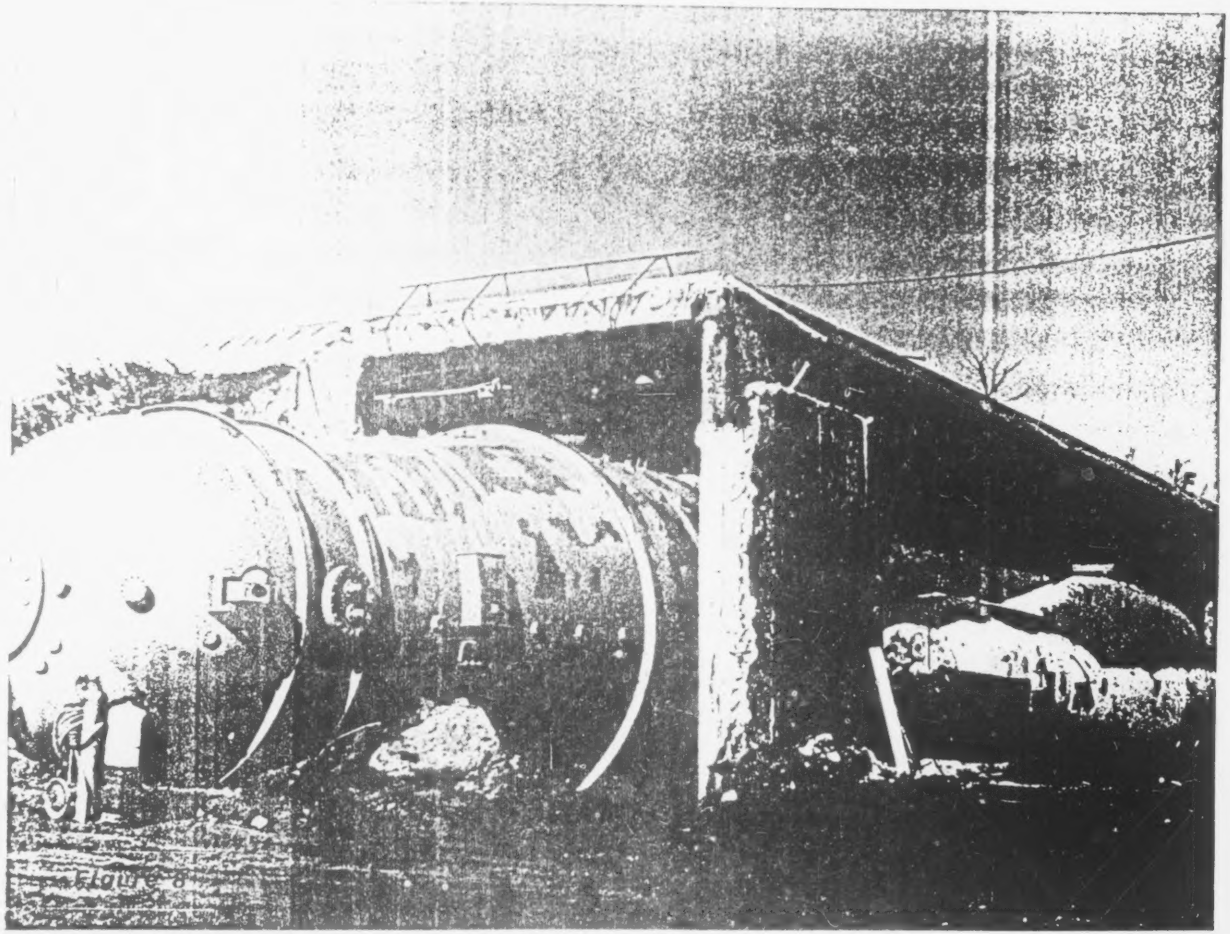


Figure 8

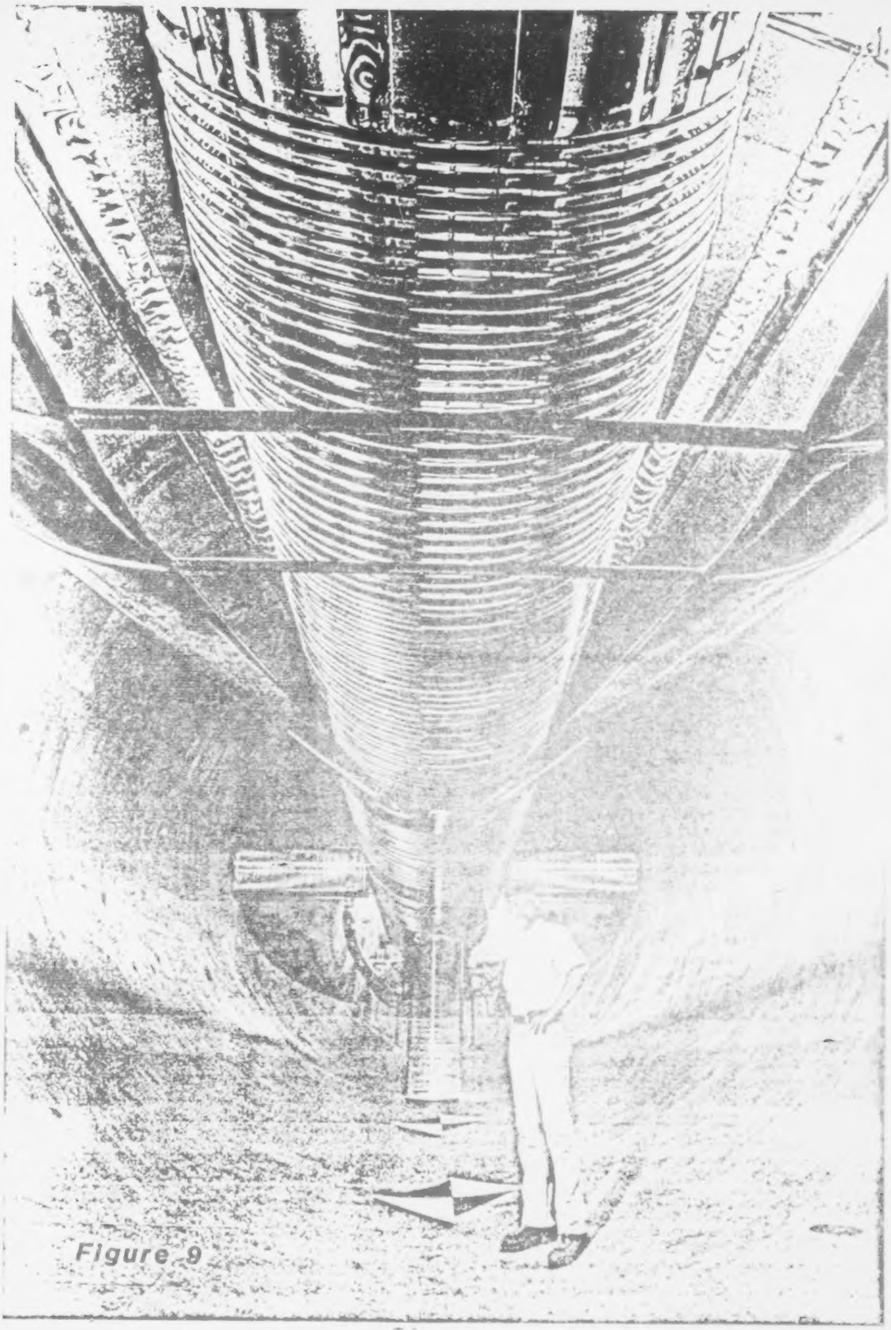


Figure 9

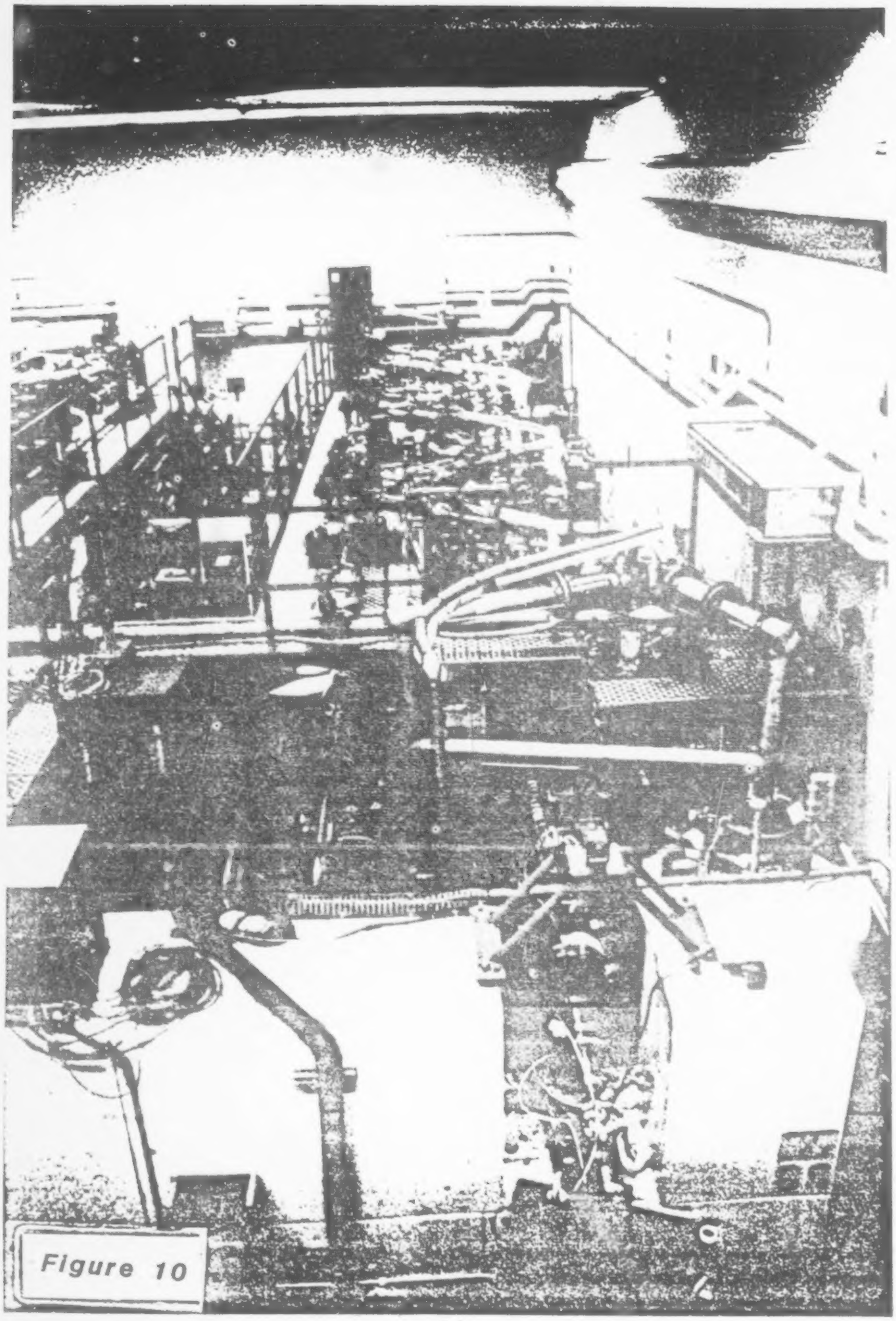


Figure 10

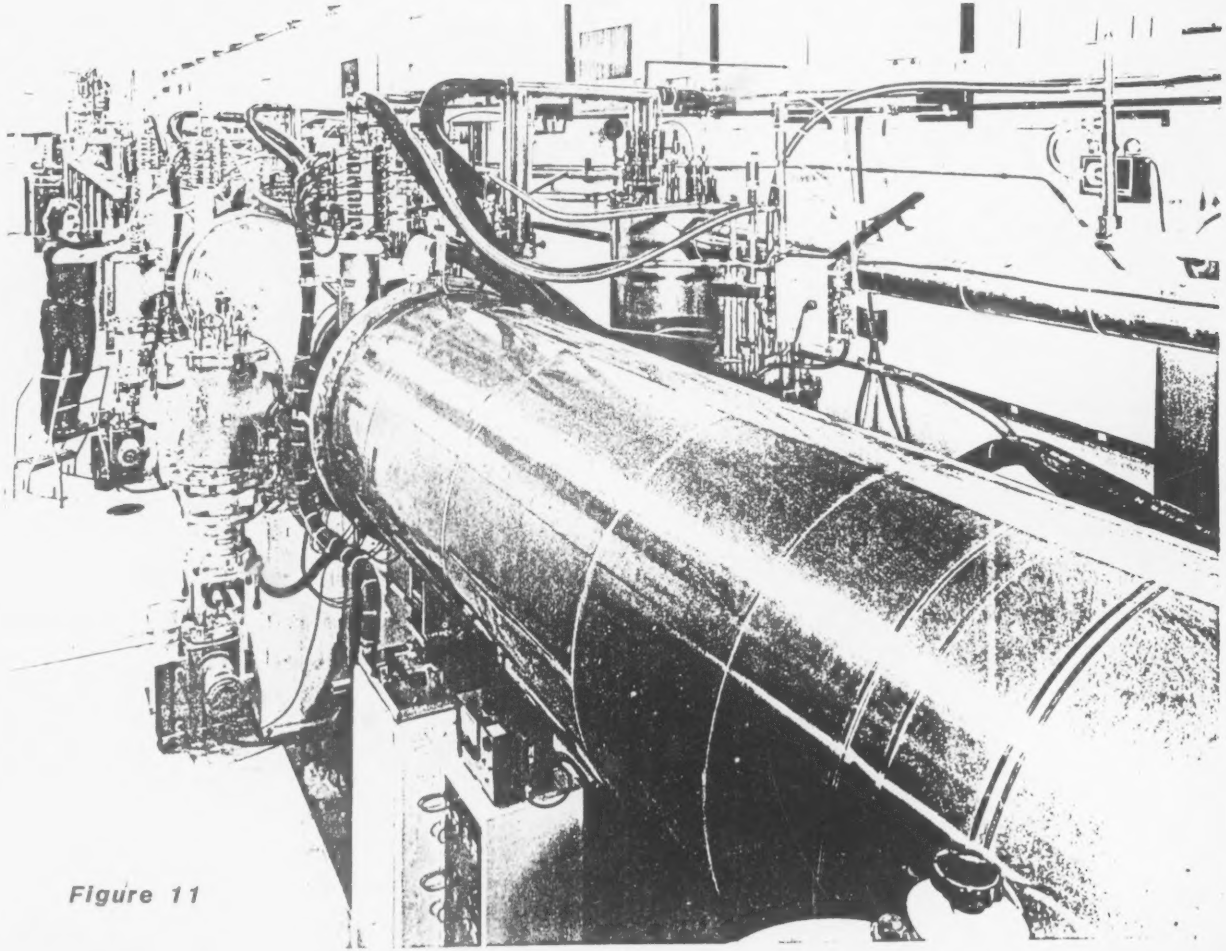


Figure 11

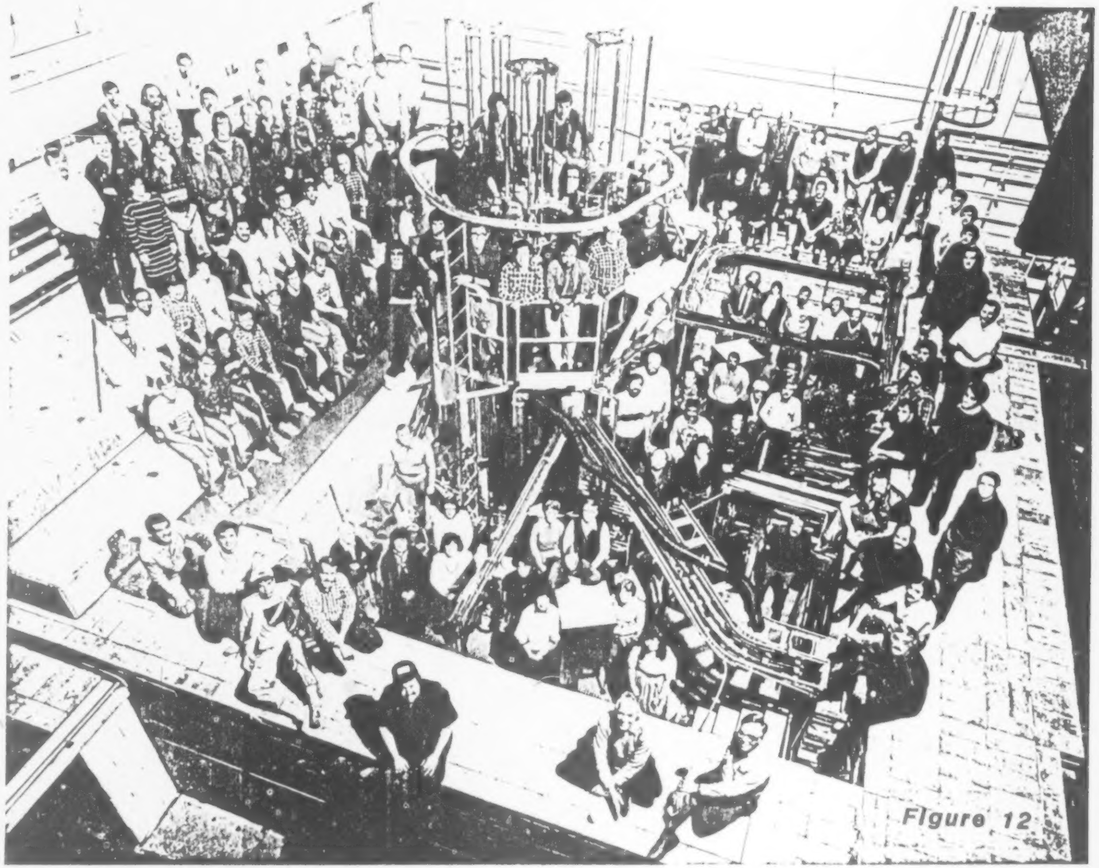


Figure 12

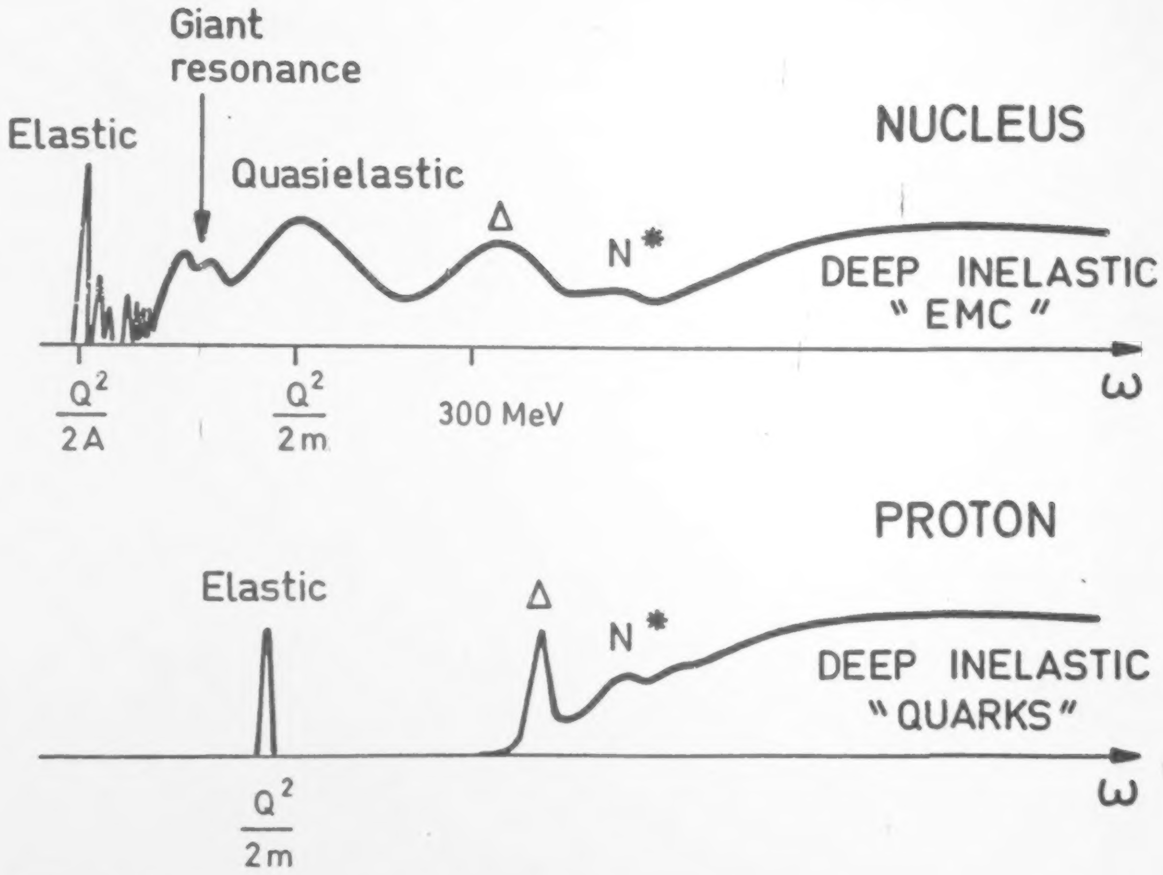

Giant
resonance
Elastic
NUCLEUS
Quasielastic
Δ
N*
DEEP INELASTIC
" EMC "
$\frac{Q^2}{2A}$
$\frac{Q^2}{2m}$
300 MeV
ω
PROTON
Elastic
Δ
N*
DEEP INELASTIC
"QUARKS"
$\frac{Q^2}{2m}$
ω

Figure 13

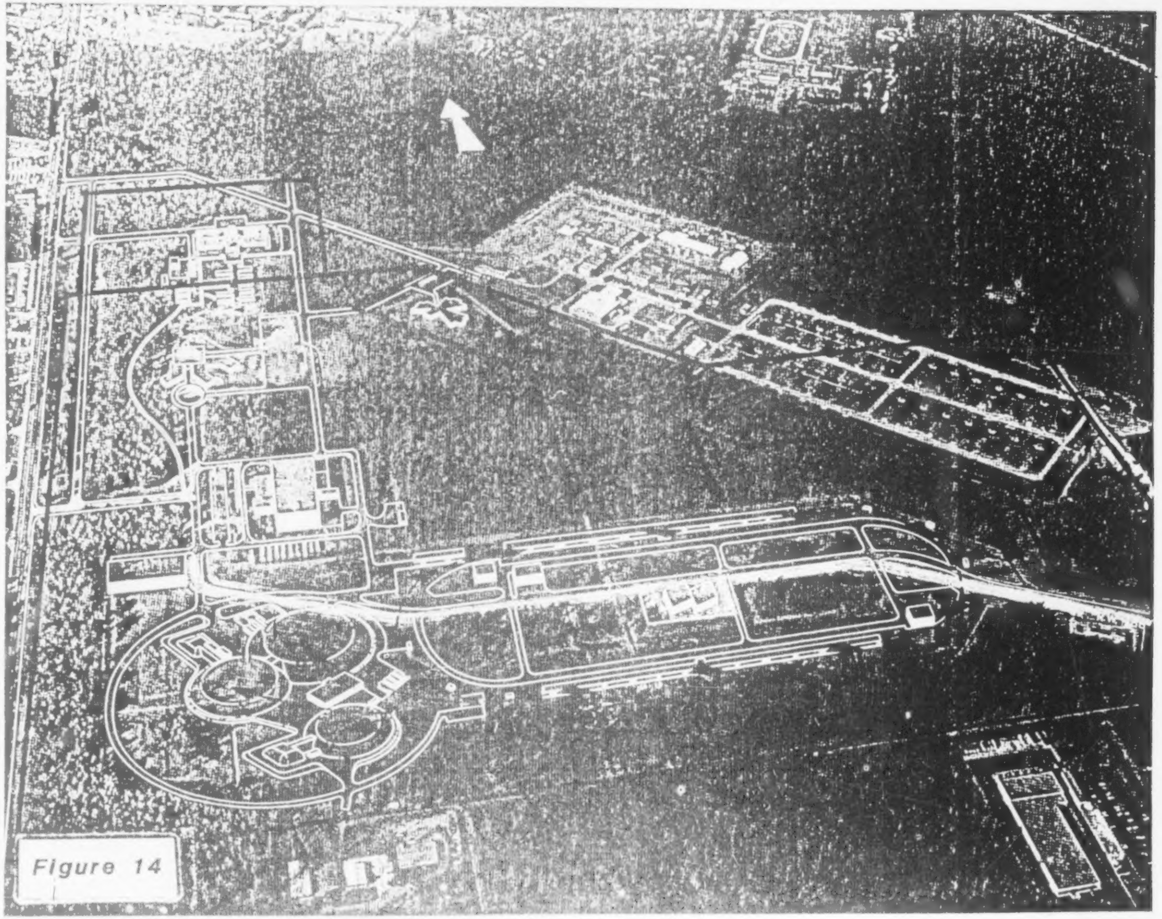


Figure 14

CEBAF Site Plan

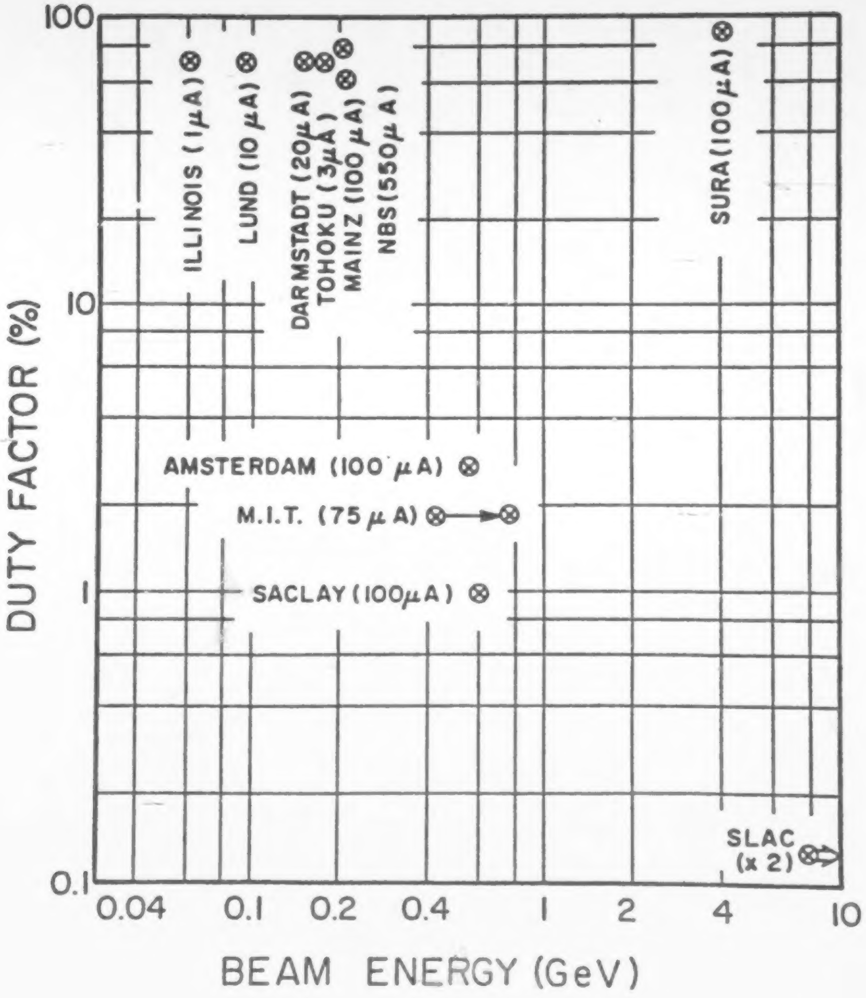

100
10
1
0.1
DUTY FACTOR (%)
0.04
0.1
0.2
0.4
1
2
4
10
BEAM ENERGY (GeV)
ILLINOIS (1μA)
LUND (10 μA)
DARMSTADT (20μA)
TOHOKU (3μA)
MAINZ (100 μA)
NBS (550 μA)
SURA (100 μA)
AMSTERDAM (100 μA)
M.I.T. (75 μA)
SACLAY (100μA)
SLAC
(x 2)

Figure 15

SCIENTIFIC MOTIVATION FOR CEBAF

- CEBAF addresses fundamental problems in nuclear physics
  - The role of mesons, excited baryons and quarks in nuclei
  - The strong force, including non-perturbative features of QCD
  - The effect of the nuclear medium on nucleon structure and quark interactions

- Electrons are precise, versatile probes of nuclear structure
  - Small cross section: $\sigma \sim 10^{-40}$ cm^2
  - Well understood interaction: QED (perturbative)
  - Probe the entire nuclear volume
  - Variable energy and momentum transfer

- CEBAF energy range explores a transition region
  - Conventional nuclear structure studies
  - Non-perturbative QCD (mesons and baryons)
  - Quark structure in nucleons

- Over 20 proposed experiments

Figure 16

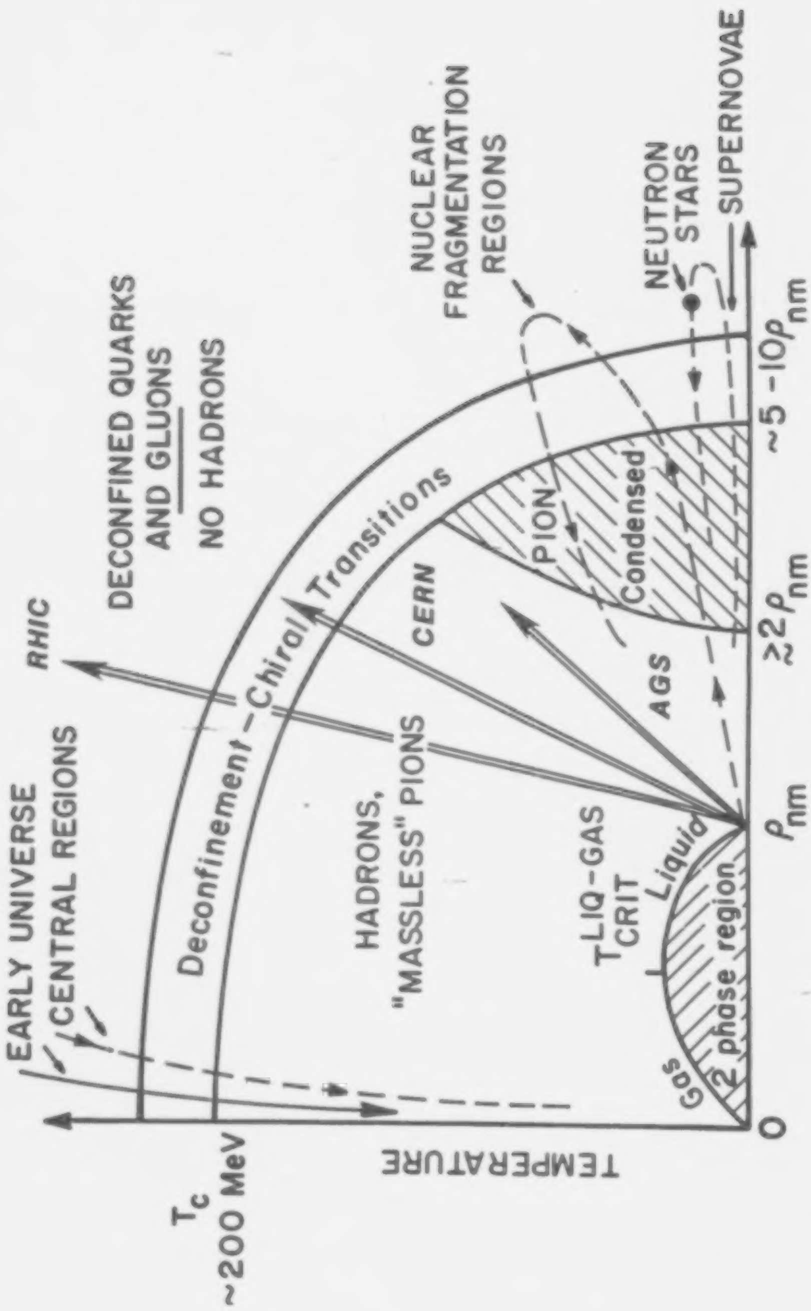

TEMPERATURE
T_c
~200 MeV
EARLY UNIVERSE
CENTRAL REGIONS
RHIC
DECONFINED QUARKS
AND GLUONS
NO HADRONS
Deconfinement—Chiral Transitions
HADRONS,
"MASSLESS" PIONS
CERN
AGS
PION
Condensed
NUCLEAR
FRAGMENTATION
REGIONS
NEUTRON
STARS
SUPERNOVAE
$T^{LIQ-GAS}_{CRIT}$
Gas
Liquid
2 phase region
0
ρ_{nm}
$\gtrsim 2\rho_{nm}$
$\sim 5-10\rho_{nm}$
BARYON DENSITY

Figure 17

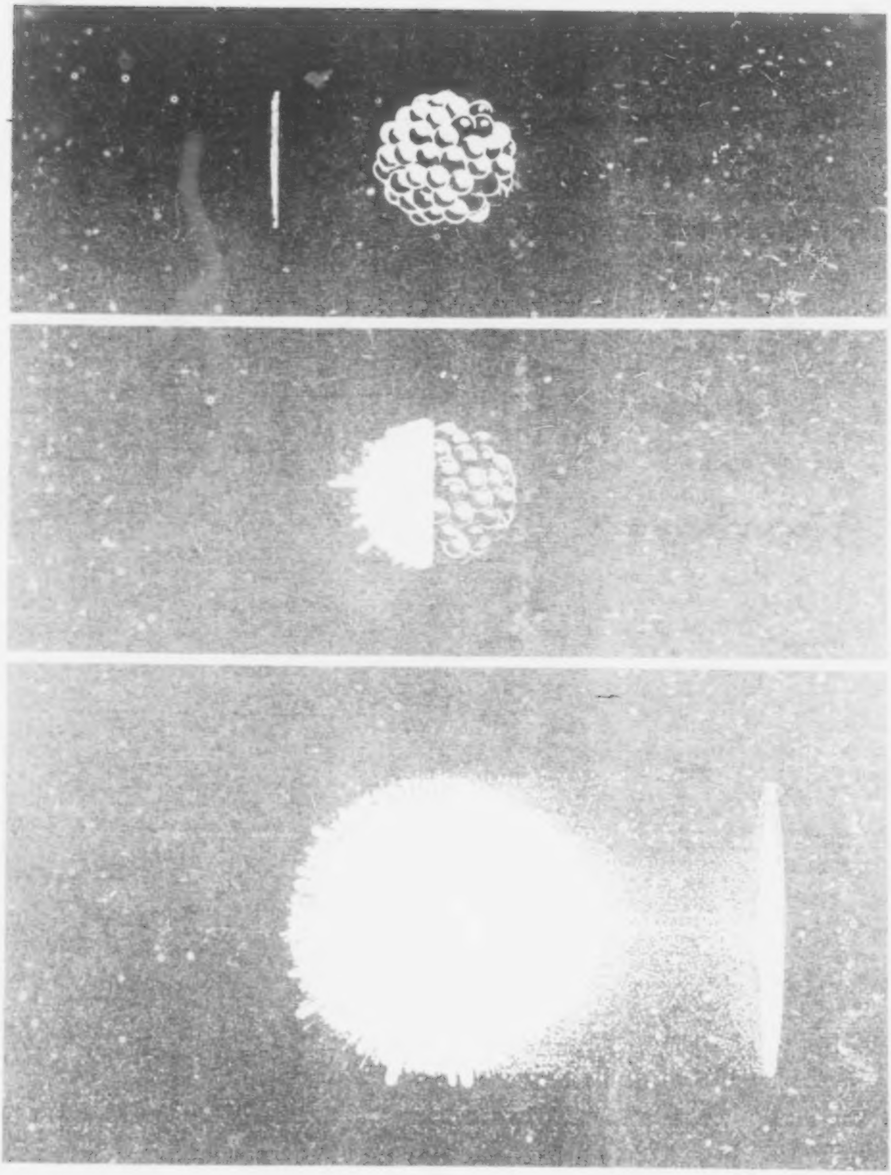


Figure 18

RELATIVISTIC HEAVY ION SCIENCE

AT BROOKHAVEN ENERGIES - 15 GeV/nucleon
- 5 GeV/nucleon C.M.

a) Projectiles are completely stopped in the target nuclei

b) Densities about 4 times normal are attained

c) Kaon/Pion ratios are greater than 20% higher than in proton-proton collisions--evidence for kaon distillation and high baryon densities

d) J/Ψ resonance is observed as evidence for production of heavy quarks and is damped by 65% in central collisions by color screening--evidence of approach to quark gluon plasma.

AT CERN ENERGIES - 200 GeV/nucleon
- 20 GeV/nucleon C.M.

a) Target nuclei are partially transparent

b) Energy densities of 1 GeV/$(\mathrm{fm})^3$ are attained - 7 times normal in nuclear matter

c) Hot core more than doubles in size--target explodes--before pions uncouple

AT RHIC ENERGIES - 100 GeV on 100 GeV
- 200 GeV/nucleon C.M.

a) Energy densities in range 3-10 GeV/$(\mathrm{fm})^3$ attainable--20 to 70 times normal

b) Densities 5 to 10 times normal are attainable

c) The quark gluon plasma is fully developed

d) The possibility of entirely new kinds of matter exists

e) Quantum chromodynamics can be tested in its perturbative limit.

Figure 19

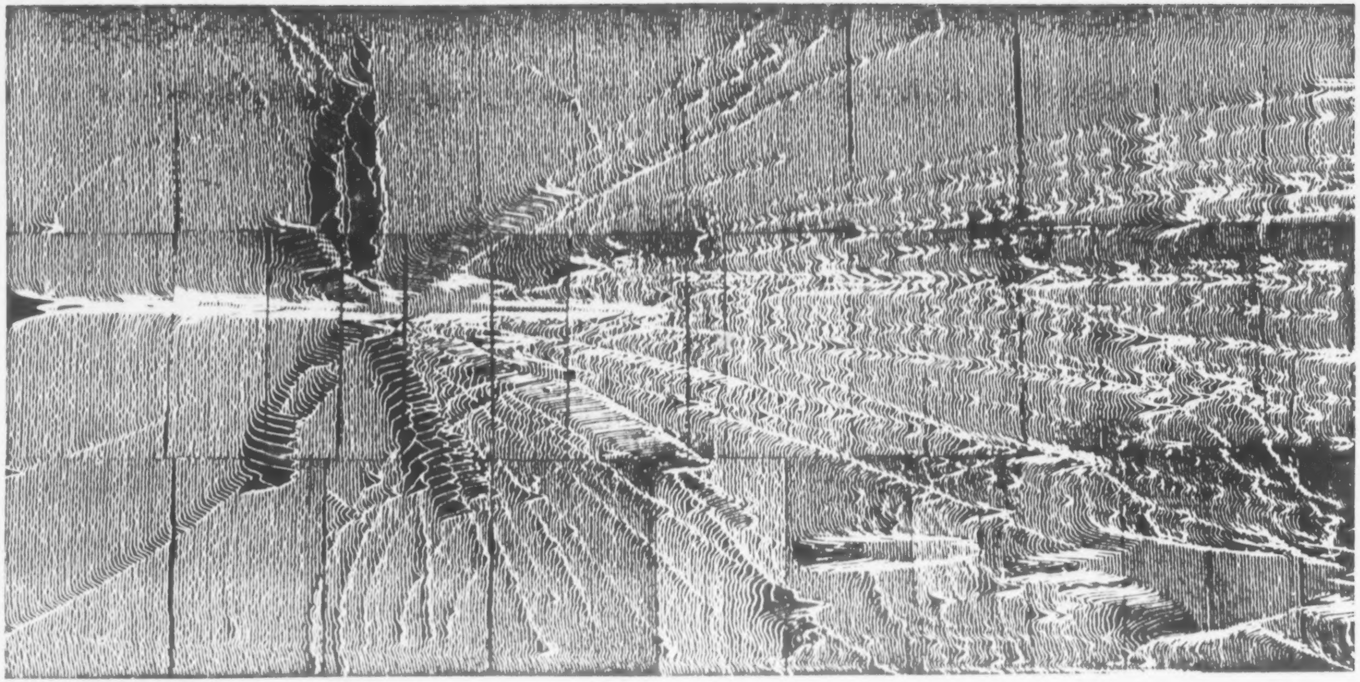


Figure 20

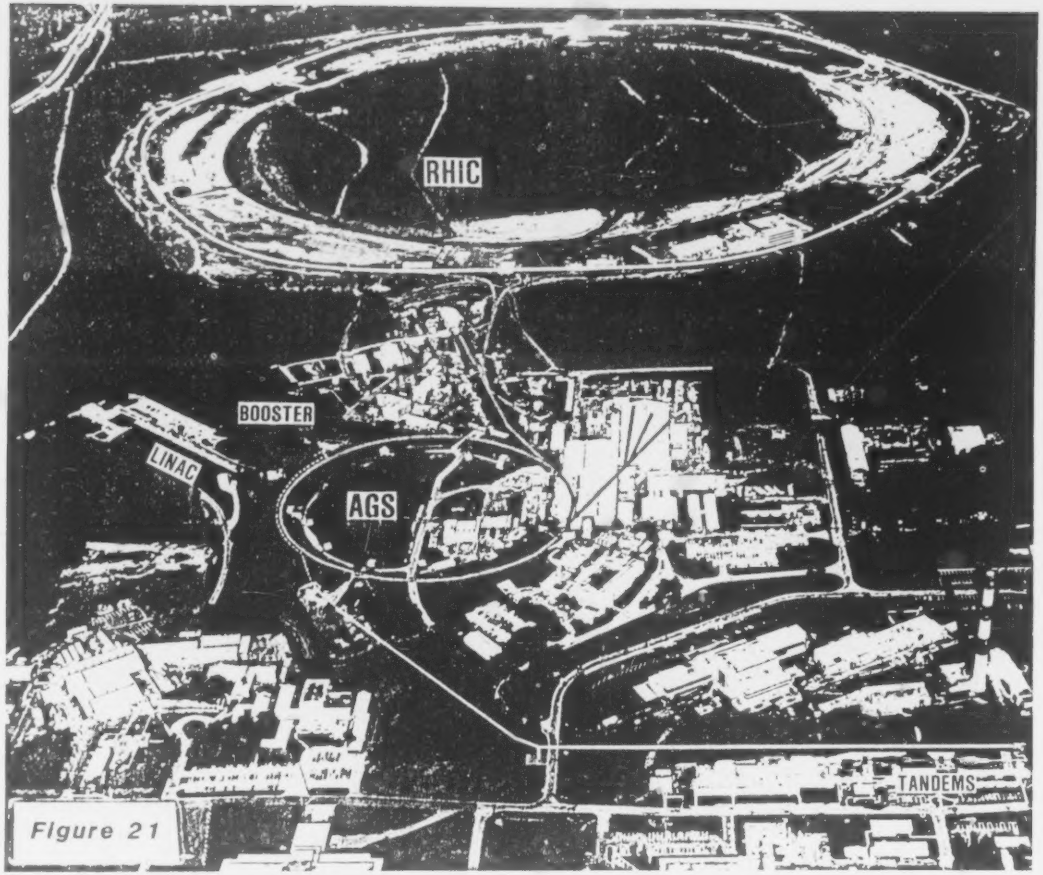

RHIC
BOOSTER
LINAC
AGS
TANDEMS

Figure 21

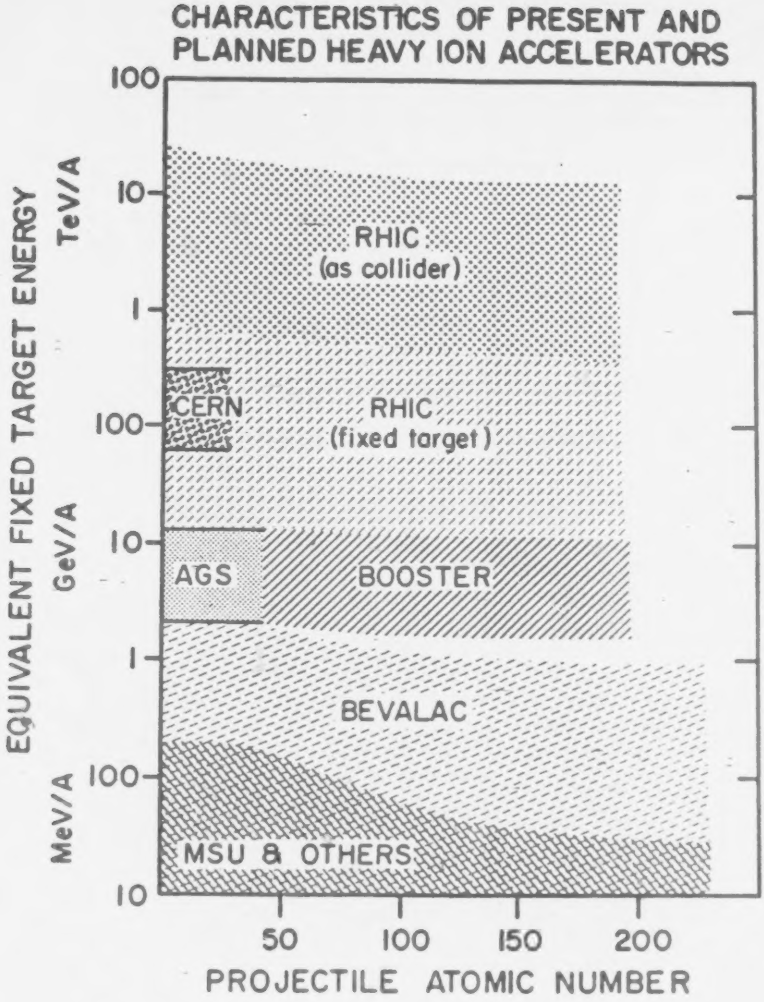

CHARACTERISTICS OF PRESENT AND PLANNED HEAVY ION ACCELERATORS
EQUIVALENT FIXED TARGET ENERGY
TeV/A
GeV/A
MeV/A
100
10
1
100
10
1
100
10
RHIC
(as collider)
CERN
RHIC
(fixed target)
AGS
BOOSTER
BEVALAC
MSU & OTHERS
50
100
150
200
PROJECTILE ATOMIC NUMBER

Figure 22

SCIENTIFIC MOTIVATION FOR RHIC

- RHIC addresses fundamental problems in nuclear and particle physics as well as astrophysics
  - the deconfinement of quarks in nuclei
  - the creation of the quark gluon plasma
  - the recreation of the early moments of creation
  - the physics of gravitational collapse of massive stars
  - the equation of state of nuclear matter
  - the possibility of entirely new kinds of matter
  - the strong force including non-perturbative QCD

- Heavy ions are uniquely powerful in such studies
  - ever increasing energy is delivered to volumes large enough to contain many nucleons (quarks) and thus permits the possibility of collective phenomena
  - wide range of projectile and target species helps in the isolation of specific interaction features and phenomena

- In using esentially all of the prior investment in CBA , RHIC is a remarkably cost effective proposal with sufficiently high energy to give clear access to the central rapidity region-the quark gluon plasma

Figure 23

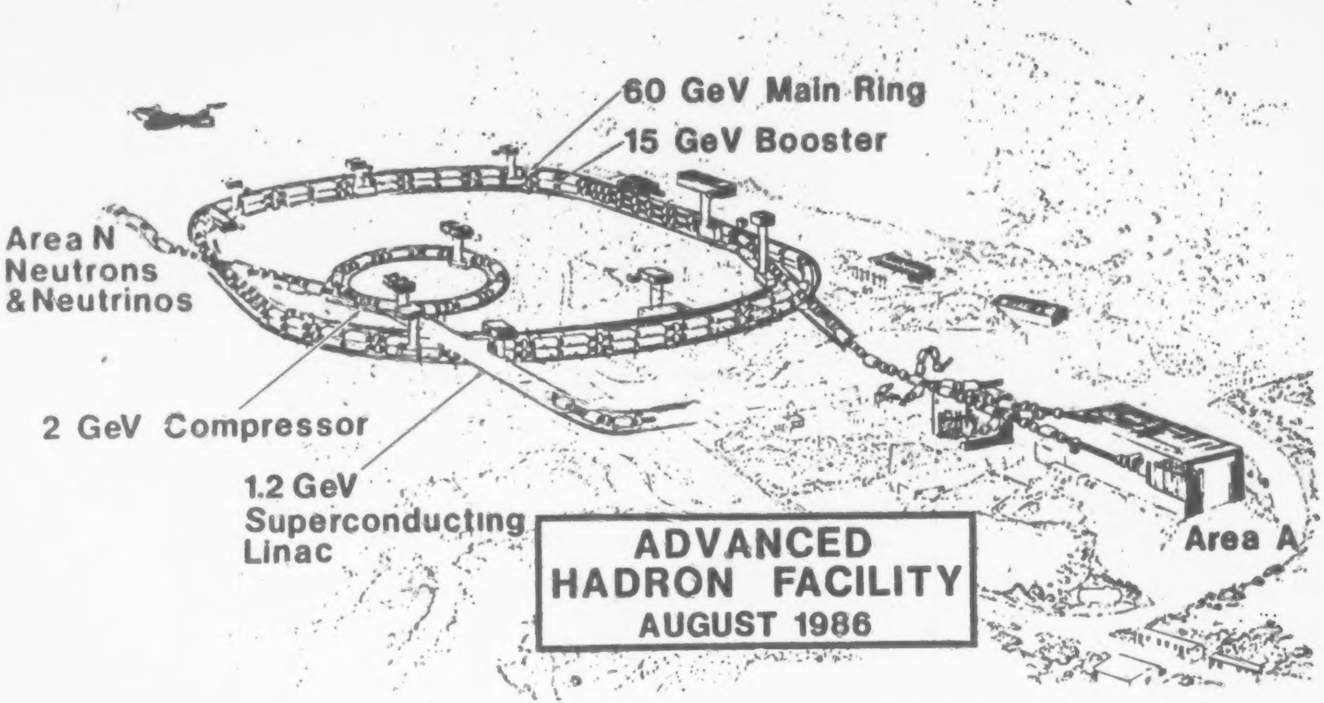

60 GeV Main Ring
15 GeV Booster
Area N
Neutrons
& Neutrinos
2 GeV Compressor
1.2 GeV
Superconducting
Linac
ADVANCED
HADRON FACILITY
AUGUST 1986
Area A

Figure 24

THE PEOPLE OF NUCLEAR PHYSICS

- REQUIRE EXPERIENCE IN BROAD RANGE OF TECHNIQUES

  Electronics, vacuum, thin films,
  detector technology, computers,
  high power radio frequency

- REQUIRE SYSTEMS APPROACH

  Progress comes only from cooperative
  efforts of engineers, technicians,
  other scientists, and colleagues

- CONFIDENCE IN ATTACKING BROAD UNSTRUCTURED PROBLEMS

  Makes those trained in nuclear physics,
  able partners in search for solutions to
  major societal and industrial problems

- NUCLEAR PHYSICS SELECTED FOR EMPHASIS IN LEADING DEVELOPED COUNTRIES

  France, Italy, Germany, Japan,
  United Kingdom

Figure 25

DEPARTMENT OF ENERGY
NUCLEAR PHYSICS BUDGET
FY 1989

- Total FY1989 Presidential request is $264.1 million representing a 7.75% increase over FY1988 — of which 4.5% represents an increase from 33.5 to 44.5 million in CEBAF construction funding.

- This represents a generous support of this science in a year when many areas are experiencing deficit reducing budget cuts.

- BUT, there are three problem areas that are of major importance to the future of this science. All reflect departures from the NSAC long range plan.

Figure 26

PROBLEM AREAS

- At a time when outstanding graduate students are turning, in increasing numbers, to nuclear physics and, when several universities are just completing major upgrading of their facilities, inadequate operating funds are forcing these university programs to turn away such students.
- The 20 million step increase in operating support recommended by NSAC--as its highest priority--in the 1983 revision of the long range plan is urgently needed both by the universities and the national laboratories.
- The CEBAF funding profile in FY1989 is 20 million less than optimal and will result in a construction stretch-out, with physics delayed by at least a year from 1993 to 1994.
- The RHIC project--a unique, world class facility--has been reviewed in detail by DOE and judged, "ready for construction". Unless this construction can be initiated in FY1989:
  - a) US scientists will lose out to CERN in the competition for access to some of the most important and exciting science in our field.
  - b) European and Japanese physicists who were prepared to become major RHIC users (and contributers) will cast their lots with other facilities in Europe and Japan.
  - c) The high quality construction staff at Brookhaven will continue to disperse.

Figure 27

THE FUTURE OF NUCLEAR PHYSICS

D. Allan-Bromley

Henry Ford II Professor of Physics
Yale University
New Haven, Connecticut 06511 USA

ABSTRACT

Nuclear physics is on the threshold of new and exciting developments stemming both from new understanding of the nuclear many-body system and new higher-energy probes—electrons, kaons and heavy-ions—that are becoming available or on the horizon. The discovery of new dynamic symmetries and the parallel establishment of an algebraic, rather than a geometric, approach has revolutionized our understanding of nuclear structure and promises a similar inpact on nuclear dynamics. The response of the nuclear system to ever increasing angular momentum and temperature is being mapped out with characteristic gross changes in shape and behavior. Higher-energy electron beams are probing the nuclear interior—long an ignored domain—and establishing the roles of meson currents and the validity of shell model concepts deep in the nuclear interior. They will soon be able to map the transition from nucleonic to quark matter within the nucleus—the appearance of nucleon isobars and their melting with the beginning of quark deconfinement. Current lattice gauge calculations predict the deconfinement phase transition at a temperature of about 200 MeV. Relativistic heavy-ion studies have already demonstrated that densities several times normal are achieved in central collisions; the next generation of experiments in this field holds promise of probing the quark-gluon plasma and of giving access to the equation of state of nuclear matter. Quantum chromodynamics may provide the key to understanding of the strong nuclear interaction at a fundamental level—perhaps equivalent to what has already been achieved in quantum electrodynamics—as new phenomena emerge at relativistic energies. But at the same time, it bears emphasis that radioactivity—double beta decay, searches for finite neutrino mass and for neutron-antineutron oscillations, for example—and studies with low-energy Van de Graaff and cyclotron accelerators continue to provide data that are critical to our understanding of nuclear phenomena. As our microscopic knowledge of nuclear structure improves, the nucleus becomes an ever more powerful microscopic laboratory wherein some of the most fundamental symmetries and interactions in nature can be subjected to quantitative tests. All contribute to the fabric of nuclear science and to the rich interfaces between nuclear and its sister sciences.

INTRODUCTION

In any field of activity, it is essential from time to time to stand back for a longer look, for better perspective. I have been asked to address that task with respect to nuclear physics. Where is it going? What does its future look like? Does it, indeed, have a future?

To this latter question, my answer must be an emphatic "Yes!" Indeed, as I shall try to illustrate in this paper, we are at a particularly interesting and promising time in the history of our science. In a very real sense, we are now in the 55th year of nuclear physics, dating back to 1932, that remarkable year with its discovery of the neutron, the deuteron, the positron, isospin, the invention of the cyclotron and the Van de Graaff; and the experimental proof of general relativity. In these 55 years, we have made incredible discoveries, and our understanding has increased at least exponentially.

But despite this progress, we tend to forget that our studies thus far have been limited: to cold nuclei near their ground states; to low-spin nuclei where centrifugal effects are negligible; to species relatively near to stability; to the surface of nuclei to particle and collective degrees of freedom involving these surfaces; and to consideration of nuclei as nucleon complexes only.

But all of this is changing rapidly: as measurements to ever-higher precision make first-order theories and understanding unacceptable; as new dynamic symmetries and perhaps supersymmetries are identified in both nuclear structure and nuclear dynamics; as new, higher-energy electron accelerators illuminate the nuclear interior, mesonic effects, nucleon isobars, and take us at least to the threshold of quark deconfinement; as new, higher-energy, heavy-ion machines illuminate high spin phenomena, take us to and beyond the limits of nuclear stability, explore the nuclear equation of state, deconfine quarks and restore chiral symmetry, recreate the earliest moments of creation, and probe the final moments of gravitational collapse; as higher-energy proton machines are used increasingly as pion and particularly kaon factories to study both nuclear structure and dynamics and the physics of hypernuclei; and as the relationship of quantum chromodynamics to the nuclear many-body system is more fully understood.

In what follows, I shall attempt to illustrate all these statements; inasmuch as I shall be spanning the entire field of nuclear physics, it will simply not be possible for me to give detailed references. The choice of illustrations will inevitably be a very personal one, and I make no claim whatever to completeness; and my examples—particularly of new facilities—will be taken primarily from U.S. experience, since I happen to be particularly familiar with it.

HEATING THE NUCLEAR SYSTEM

One of the problems of longest standing in nuclear physics is that of understanding what happens as energy and angular momentum are added to the nuclear many-body system. This general behavior is illustrated in Fig. 1 where I take as an example the 56-body ^{56}Ni system and illustrate schematically the gross changes that are expected with increasing temperature and spin. Close to the ground state, the valence nucleons and surface collective modes absorb the added energy, but with further heating, the nucleus becomes an oblate spheriod and spins collectively; at still higher temperatures the nuclear shape changes abruptly to that of a prolate spheroid, and in the case of ^{56}Ni, we now know that even up to excitation energies of some 70 MeV, very sharp quantum states are superimposed on a dense continuum. Some of these states have been shown to correspond to a spontaneous separation of the 56 nucleons into two identical ^{28}Si subnuclei which engage in simple molecular motion relative to one another. Other states, only a few hundred keV different in total energy, have been shown to correspond to a spontaneous separation into ^{16}O and ^{40}Ca clusters, and although they have not been specifically identified, it seems obvious that there are many other binary and more complex cluster structures that emerge spontaneously. No one knows how far these sharp cluster or molecular states extend into the nuclear continuum; all that can be said at this point is that wherever probes have been available with adequate resolution to see these sharp states, the states have appeared.

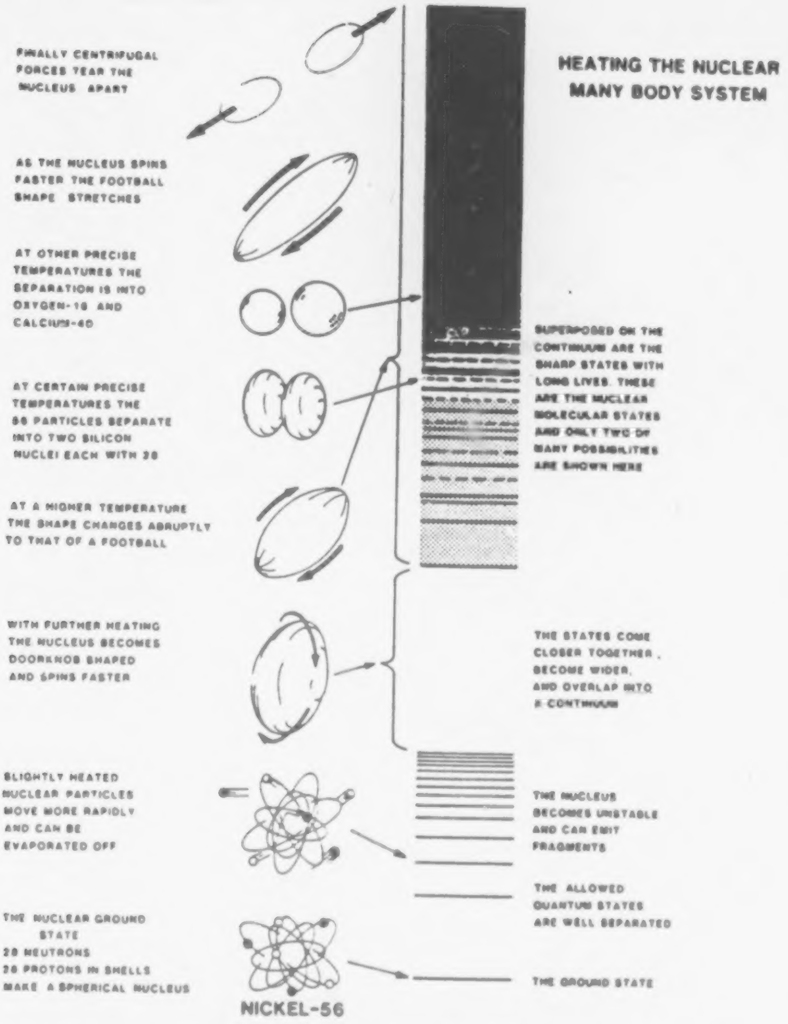
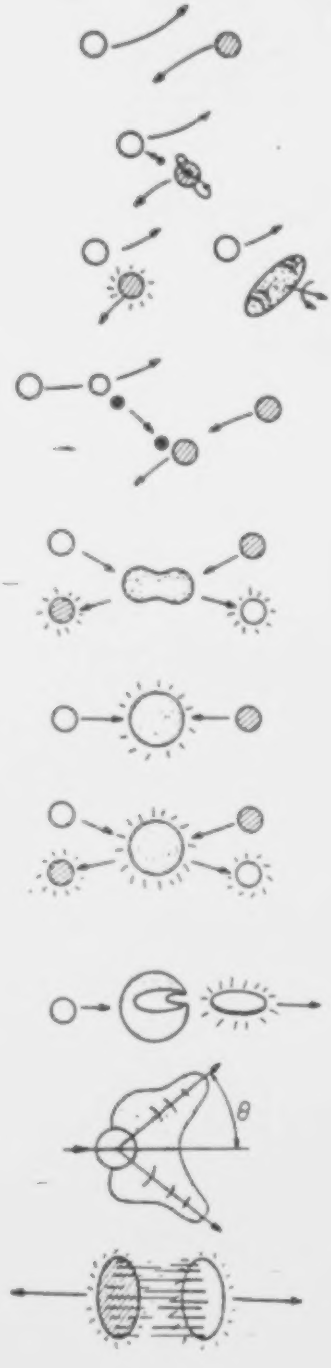

HEATING THE NUCLEAR MANY BODY SYSTEM
FINALLY CENTRIFUGAL FORCES TEAR THE NUCLEUS APART
AS THE NUCLEUS SPINS FASTER THE FOOTBALL SHAPE STRETCHES
AT OTHER PRECISE TEMPERATURES THE SEPARATION IS INTO OXYGEN-16 AND CALCIUM-40
AT CERTAIN PRECISE TEMPERATURES THE 56 PARTICLES SEPARATE INTO TWO SILICON NUCLEI EACH WITH 28
28
AT A HIGHER TEMPERATURE THE SHAPE CHANGES ABRUPTLY TO THAT OF A FOOTBALL
WITH FURTHER HEATING THE NUCLEUS BECOMES DOORKNOB SHAPED AND SPINS FASTER
SLIGHTLY HEATED NUCLEAR PARTICLES MOVE MORE RAPIDLY AND CAN BE EVAPORATED OFF
THE NUCLEAR GROUND STATE
28 NEUTRONS
28 PROTONS IN SHELLS
MAKE A SPHERICAL NUCLEUS
NICKEL-56
SUPERPOSED ON THE CONTINUUM ARE THE SHARP STATES WITH LONG LIVES. THESE ARE THE NUCLEAR MOLECULAR STATES AND ONLY TWO OF MANY POSSIBILITIES ARE SHOWN HERE
THE STATES COME CLOSER TOGETHER, BECOME WIDER, AND OVERLAP INTO A CONTINUUM
THE NUCLEUS BECOMES UNSTABLE AND CAN EMIT FRAGMENTS
THE ALLOWED QUANTUM STATES ARE WELL SEPARATED
THE GROUND STATE

Figure 1: A schematic illustration of the change in nuclear structure with increasing excitation energy and angular momentum for the 56 body system ^{56}Ni. The increased shading with excitation energy is intended to represent the exponentially increasing level density with excitation, and the sketches to the left of the level diagram are highly schematic representations of gross structural features.

As the nucleus spins faster, the prolate spheroid stretches and eventually, at some critical angular momentum, the nucleus spontaneously disintegrates under centrifugal forces. In the case of ^{56}Ni, simple calculations suggest that this happens at a total angular momentum of roughly $50\hbar$ which is only some 6 units beyond spin values that have now been identified unambiguously in this system.

While Fig. 1 focuses on the structure of nuclei, Fig. 2 provides a corresponding overview of nuclear interactions and dynamics ranging from the most simple to the most complex. Elastic scattering, governed by the Coulomb interaction, is of course the simplest possible interaction in that it involves no nuclear degrees of freedom at all. This is followed by nucleon transfer, inelastic scattering and cluster transfer. More complex is quasifusion and deep inelastic



ELASTIC SCATTERING
no internal excitation

NUCLEON TRANSFER
one or at most a few degrees
of freedom involved

INELASTIC SCATTERING
rotations, vibrations and surface
collective modes involved

CLUSTER TRANSFER
opens way to more complex
molecular type configurations

QUASIFUSION DEEP INELASTIC
involves massive exchange of
mass and energy but far from
thermodynamic equilibrium.
Friction enters the quantum domain

FUSION COMPOUND NUCLEUS
approaches thermodynamic equilibrium,
memory of formation lost

FUSION-FISSION
fission following equilibration but
increasing evidence for fission before
full fusion , important intermediate
processes

HIGH ENERGY FIREBALL
projectile gouges a hot section out
of an otherwise spectator remnant

HIGHER ENERGY COMPRESSION
shock phenomena lead to characteristic
sidesplash or Mach angle emission and
to densities substantially greater than
normal . Possible new forms of matter

ULTRA HIGH ENERGY
QUARK-GLUON PLASMA
projectile and target pass completely
through one another leaving baryon
free central firetube:
quark deconfinement, quark gluon plasma

Figure 2: An overview of nuclear interactions ranging from the simplest—elastic scattering—to the most complex at ultrahigh energies. Again the figures are very highly schematic representations of the interactions involved.

scattering where substantial exchange of mass and energy takes place; but the system still remains far from thermodynamic equilibrium. This, too, is the regime where the last of the classical parameters—friction—enters the quantum domain. Next comes complete fusion and the formation of a compound nucleus where it is still assumed that the famous Bohr hypothesis of complete thermodynamic equilibration holds. There is, however, increasing evidence for significant reaction flux via a mechanism which approaches fusion but does not complete it, and wherein, after significant exchange of energy and matter, the projectile and target separate again in a quasifission process.

In moving to substantially higher energies, there is convincing evidence that, particularly in peripheral interactions, the projectile shears a sector out of the target, heating it to very high temperatures in the process with subsequent particle evaporation and emission from the hot fragment while the remainder of the target plays a passive, spectator role. At even higher energies, recent measurements which have separated out central collisions from the much more probable peripheral ones demonstrate clear evidence for hydrodynamic shock formation with characteristic shock flow angles and compression leading to densities several times that normal in nuclear matter. Finally, at ultrahigh energy, nuclei become transparent to one another, and in collisions at these energies, projectiles and target, can pass completely through one another, heating both to very high temperatures and leaving a central fire tube having essentially zero baryon number and deconfined quarks in an effective quark-gluon plasma—an entirely new form of matter.

Figure 3 represents a different and still instructive gross characterization of nuclear phenomena in terms of the nuclear size (proportional to $A^{1/3}$) and the

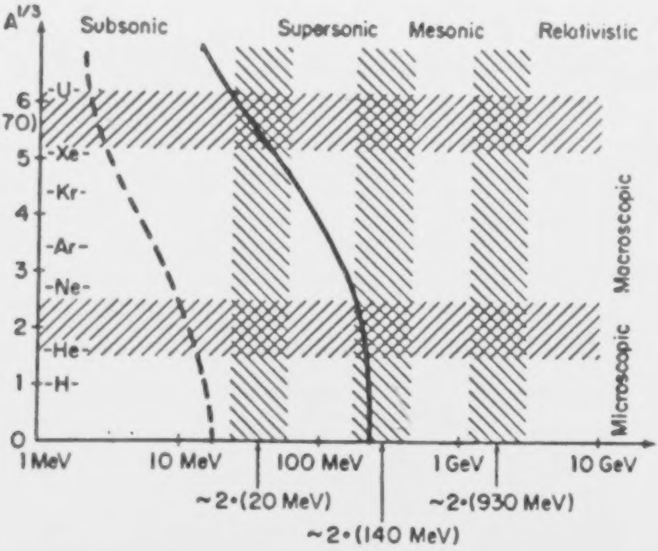


Figure 3: The nuclear energy regime with size plotted against available energy. The shaded bands are very roughly defined and intended only to separate crudely different behavioral regimes. All the area to the left of the dashed line is accessible to an Emperor tandem accelerator, while all that to the left of the solid black line is accessible to the Michigan State cyclotrons and the entire diagram below some 2 GeV per nucleon, is accessible to the Berkeley Bevalac. The upper horizontal shaded band simply indicates the size at which in identical particle collisions the Coulomb field would be expected to become supercritical.

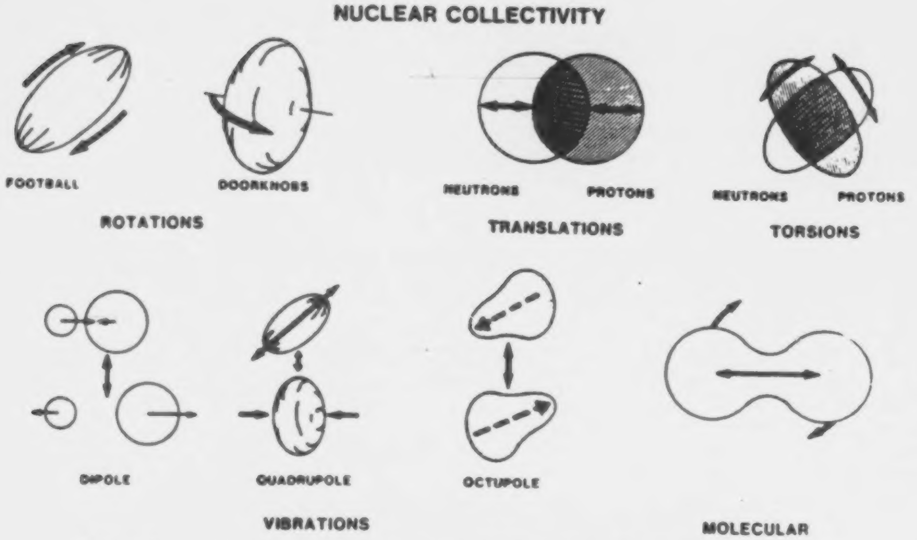


Figure 4: A schematic illustration of the primary varieties of nuclear collectivity. Rotations and vibrations are those familiar in the nuclear liquid drop model, the translational oscillation gives rise to the giant nuclear resonance while the torsional oscillation is the so-called scissors mode recently discovered in rare-earth nuclei. In molecular collectivity the participant nuclei retain their individual characteristics in large measure and undergo both vibrations and rotation much as in the atomic case.

available energy. The subsonic regime is that familiar in classical nuclear physics and extends up to roughly 20 MeV per nucleon, while the supersonic range in which nucleon velocities exceed that of sound in nuclear matter extends up to the meson threshold at about 140 MeV per nucleon. Relativistic phenomena become important above the rest mass of the nucleon at about 930 MeV. Considering the size variable, microscopic phenomena are those involved with projectiles lighter than say lithium, and on this figure, I have indicated the size where identical particle collisions give a combined atomic number of approximately 170 and where in consequence the Coulomb field becomes supercritical. The area to the left of the dashed curve on this figure is that accessible to an MP class tandem Van de Graaff accelerator; that to the left of the solid curve is that accessible to the Michigan State coupled cyclotron system, while the entire diagram below energies of roughly 2 GeV per nucleon is accessible to the Bevalac accelerator.

NUCLEAR SPECTROSCOPY AT HIGH ANGULAR MOMENTUM

With the recognition of nuclear collective degrees of freedom in the early 1950s, much of the low-lying quantum excitation of relatively cold nuclei has been understood in terms of relatively simple collective rotations and vibrations. Figure 4 shows schematic illustrations of the most important of these. Perhaps the most striking collective motion is the simple rotation of oblate and prolate quadrupole deformed nuclei. The giant resonance in nuclei has been recognized for an even longer time as a simple collective excitation wherein the neutron and proton fluids oscillate coherently in translation against one another, leading to separation of the centers of mass and charge, and therefore, to an electric dipole moment. Only within the past few years has it been recognized that in the case of deformed nuclei, the neutron and proton fluids can execute a torsional oscillation with respect to one another in the so-called scissors mode. While the giant resonance is found typically from 14 to 20 MeV in excitation, the scissors mode is found at about 3 MeV in the rare earth nuclei, for example. Molecular collective oscillations are those wherein the participant nuclei retain their intrinsic characteristics while

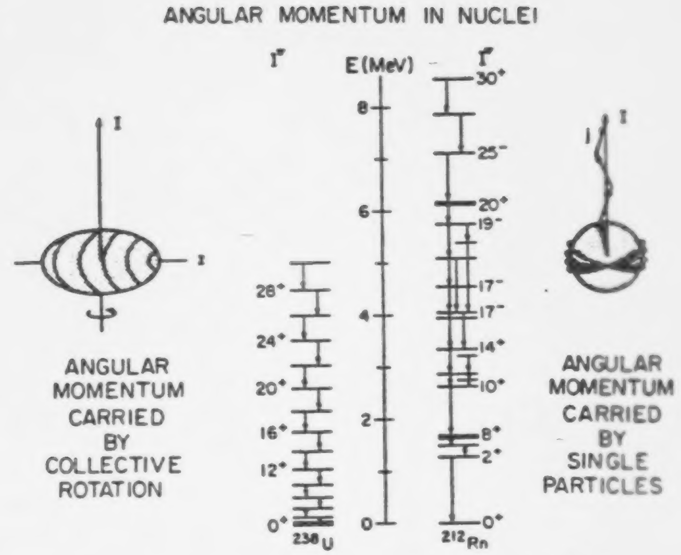
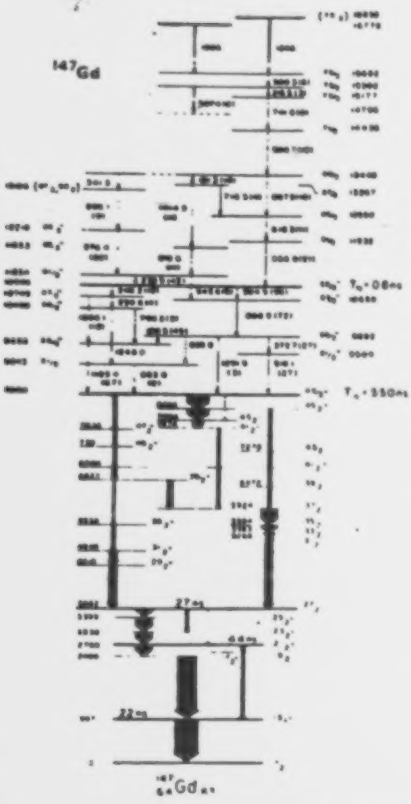

ANGULAR MOMENTUM IN NUCLEI
I
I
ANGULAR MOMENTUM CARRIED BY COLLECTIVE ROTATION
I^{π}
28⁺
24⁺
20⁺
16⁺
12⁺
0⁺
^{238}U
E(MeV)
8
6
4
2
0
I^{π}
30⁺
25⁻
20⁺
19⁻
17⁻
17⁻
14⁺
10⁺
8⁺
2⁺
0⁺
^{212}Rn
I
I
ANGULAR MOMENTUM CARRIED BY SINGLE PARTICLES

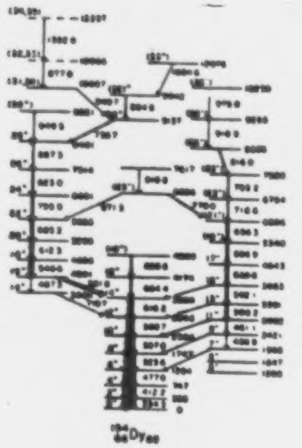
Figure 5a: A schematic illustration of the way in which the nuclear many-body system responds to increased angular momentum. Two quite distinct mechanisms are involved. On the left is the case where increased angular momentum is accommodated through increased angular velocity of the nucleus, rotating effectively as a rigid body, whereas on the right, increased angular momentum is accommodated by sequential realignment of individual particle orbits, so that their angular momentum can add coherently to the total of the system. The characteristic excitation spectra are illustrated for the two cases with those of ^{238}U and ^{212}Rn respectively.

executing standard molecular rotations and vibrations. Finally, vibrations of many multiple orders have been recognized with the quadrupole one being of greatest importance and longest standing; only within the past few years has it been discovered that collective dipole vibrations occur in the vicinity of closed shells where valence alpha particles and perhaps heavier fragments oscillate with respect to the remaining core nucleus. During this same period, there has also been growing evidence for the existence of both dynamic and static octupole deformations, the former—with the dipole collective configurations—corresponding to reflection asymmetric intrinsic shapes.

All of these collective excitations are now relatively well understood, both macroscopically and microscopically.

Particularly with the availability of precision heavy-ion accelerators, it has become possible to add very large amounts of angular momentum to the nuclear system without simultaneously adding so much energy that the system disintegrates spontaneously; this has made possible spectroscopy at very much higher angular momentum than was previously accessible. How then does the nuclear many-body system accommodate this increased angular momentum? As illustrated in Fig. 5a, there are two quite distinct mechanisms: in the first, the angular momentum is carried by collective rotation of the entire nucleus, resulting in a very regular and characteristic rotor spectrum as shown for the case of ^{238}U; the second is more complex in that the increasing angular momentum is carried by the sequential alignment of single particle orbitals so that their angular momentum adds to the nuclear total. This latter mechanism results in a very irregular excitation spectrum as illustrated here for the case of ^{212}Ra.





^{147}Gd: G. Sletten **et al.** Niels Bohr Institute
P. Chowdhury **et al.** Argonne Nat. Lab.
Y.H. Chung **et al.** Purdue Univ.
Phys. Letters **135** 33, 1984

^{154}Dy: A. Pakkanen **et al.** Purdue Univ.
P. Chowdhury **et al.** Argonne Nat. Lab.
D.C. Radford Yale Univ.
Phys. Rev. Letters **48** 1530, 1982

Figure 5b: An illustration of collective and single-particle structure in typical rare-earth nuclei. In the case of ^{147}Gd, the structure below the isomeric state at 8.5 MeV is purely collective, while that at higher excitation is typical of that resulting from alignment of single particle orbitals. In the case of ^{154}Dy, all of the indicated excitation-spectrum is of collective origin excepting the states at 10.1 and 11 MeV deexcited by electric dipole transitions. These and the states above them are of aligned particle origin.

Figure 5b illustrates these two types of behavior in two well-studied rare-earth nuclei, ^{147}Gd and ^{154}Dy. In the case of ^{147}Gd, the structure is clearly collective up to the isomeric state at 8.5 MeV and dominated by a single-particle phenomenon at higher excitation energies. In the case of ^{154}Dy, the entire low-energy spectrum is clearly collective up to the states at 10.0 and 10.9 MeV where single-particle phenomena are first identified.

From measurements such as these, it has become possible to map out the general behavior expected as both neutrons and angular momenta are added to closed shell nuclei. In Fig. 6, this is illustrated for the case of the dysprosium isotopes; the shaded region is that which has thus far been studied in detail, and it is clear that a very large unknown region is still open for exploration. At low angular momentum, on adding neutrons to the magic N = 82 system, a range of vibrators is encountered, followed by deformed prolate rotors. As the angular momentum is increased, at low neutron numbers the higher angular momentum is encompassed by aligning valence particle orbitals with respect to a deformed oblate core. With larger neutron number, the particle orbits are aligned with respect to a static prolate deformation, and although there is no concrete experimental

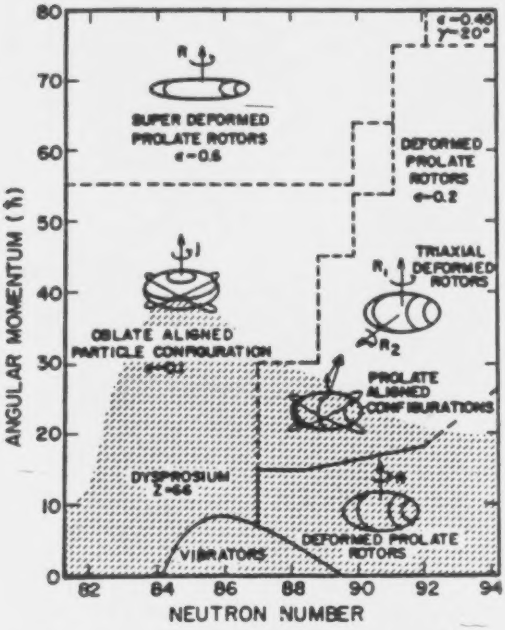

ANGULAR MOMENTUM (ħ)
NEUTRON NUMBER
0
10
20
30
40
50
60
70
80
82
84
86
88
90
92
94
ε~0.46
γ~20°
R
SUPER DEFORMED PROLATE ROTORS ε~0.6
DEFORMED PROLATE ROTORS ε~0.2
I
TRIAXIAL DEFORMED ROTORS
R₁
R₂
OBLATE ALIGNED PARTICLE CONFIGURATION ε~0.1
PROLATE ALIGNED CONFIGURATIONS
DYSPROSIUM Z=66
R
VIBRATORS
DEFORMED PROLATE ROTORS

Figure 6: A schematic representation of the shapes of dysprosium isotopes as a function of angular momentum and neutron number. The shaded region is that studied experimentally thus far, while the unshaded region remains a matter of conjecture. The indicated dividing lines are extremely crude and based on simple model predictions.

evidence as yet, it is anticipated that, with increasing angular momentum and large neutron number, triaxial rotor configurations will be involved. Whatever the neutron number, at sufficiently high angular momentum centrifugal forces can be expected to lead to superdeformed prolate rotors, in general showing axial symmetry, except in the case of very large neutron number where there is the possibility of sustained triaxiality. An enormous amount of work remains to be done in mapping out this domain across the periodic table.

The availability of new generations of gamma-ray detectors, including the shielded bismuth germinate (BGO) units has in the recent past led to a renaissance in the study of discreet gamma-ray spectroscopy at high excitation and at high angular momentum. Figure 7 is typical of recent measurements on odd- and even-mass dysprosium—in this case, work from the Copenhagen group—and again illustrating striking collective behavior.

Figure 8, showing very recent work of Twin and his collaborators at the Daresbury Laboratory in England, is a magnificient technological tour de force in that for the first time it demonstrates very clearly discreet gamma-ray lines from states in ^{152}Dy at angular momenta up to 60ħ, far beyond any previously observed. These spectra demonstrate the power of the BGO units when coupled with heavy-ion reactions induced by projectiles such as ^{48}Ca. Figure 9 plots the yrast states as determined from the spectra of Fig. 8 showing the crossing of the low deformation band by a superdeformed rotational band of much higher moment of inertia. These measurements open up an entirely new domain of study of nuclear structure where centrifugal forces more nearly balance the nuclear binding and make possible much more sensitive probing of the microscopic structure at high angular momentum than has previously been possible.

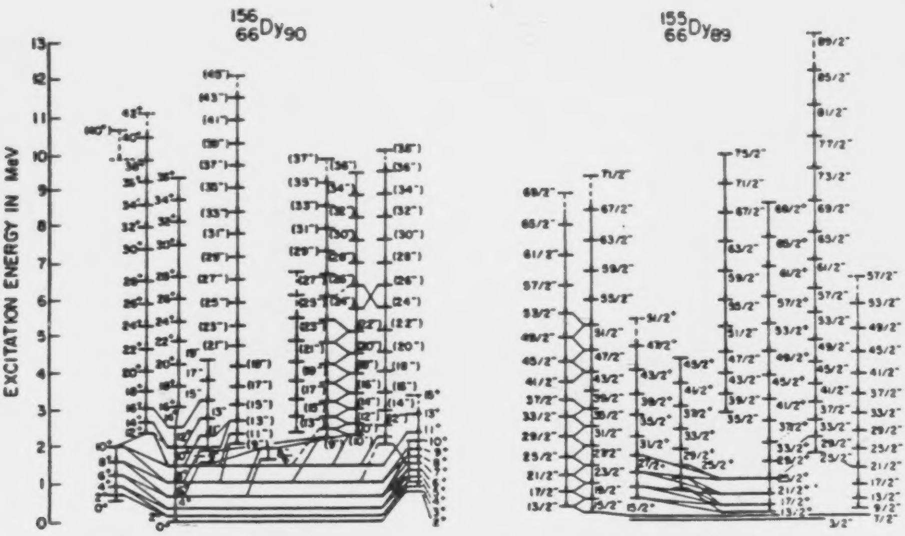


Figure 7: Typical modern spectroscopy of rare-earth nuclei. These data were obtained by a Copenhagen group working at the Daresbury National Laboratory in the United Kingdom and are typical of modern studies on even- and odd-mass, rare-earth nuclei, respectively.

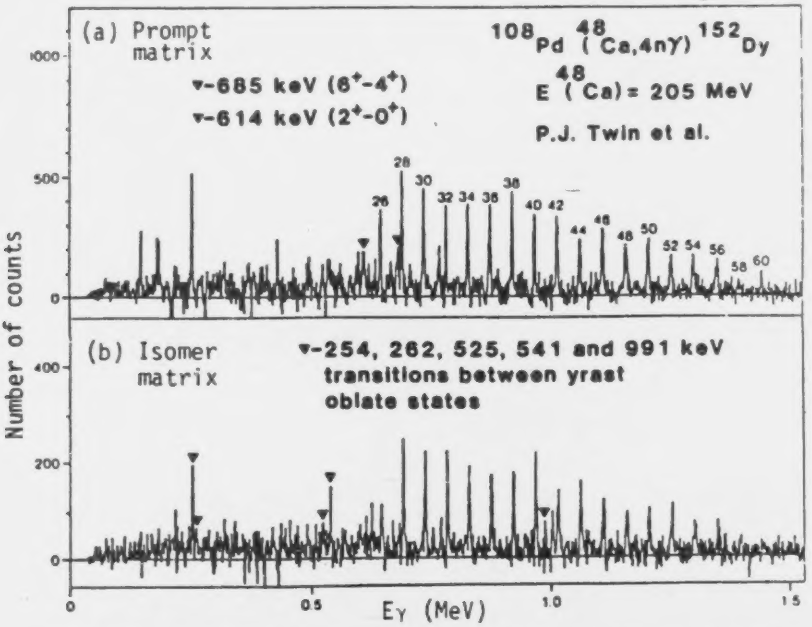


Figure 8: Very recent data from the Daresbury National Laboratory obtained using a large BGO gamma detection array and 205 MeV ^{48}Ca projectiles on ^{108}Pd targets. The numbers in the upper panel indicate the angular momentum, in units of ℏ, of the initial state in the transition. The transitions indicated by the inverted triangles are identified in the partial spectrum shown in Figure 9.

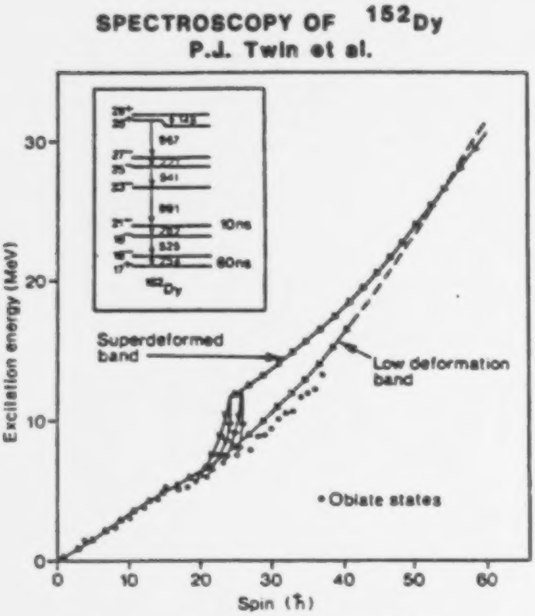


Figure 9: Yrast spectroscopy in ^{152}Dy. Both the normal low deformation band and the superdeformed (see Fig. 6) are shown, as are the oblate states along the yrast line. The transitions shown in the inset in this figure are identified by the inverted triangles in Fig. 8. These data represent, by a substantial margin, the highest angular momenta that have yet been identified unambiguously in nuclear physics.

Of particular importance here is the fact that recent theoretical calculations, using modern quantum chaos and information theory techniques, by Alhassid and his collaborators at Yale have predicted the occcurrence of phase transitions and tricritical points in the high spin spectrum of deformed nuclei. Such phenomena, if they are indeed present, should be clearly discernible in discreet spectra similar to those shown in Fig. 8.

Up until these recent data of Twin et al. shown in Fig. 8, the record in nuclear physics for the highest unambiguously identified angular momenta was established in measurements on the elastic scattering of silicon on silicon, as mentioned above in conjunction with Fig. 1. Figure 10 shows, at the upper left, data of Betts et al. at Yale and at lower left a much higher resolution expansion of the shaded region taken with adequate resolution to show the sharp molecular states mentioned previously in the ^{56}Ni compound nucleus. The spins of these compound states were established from the elastic scattering angular distributions shown on the right of Fig. 10 where as each new partial wave becomes active the angular distribution can be represented almost precisely by the square of the corresponding Legendre polynomial. Interest here centers on the fact that spontaneous centrifugal disruption of the compound system would be expected at a total spin of 50 units which will be readily attainable with the larger electrostatic accelerators now just coming into operation. Fig. 11 again shows the sharp structure in the ^{56}Ni as well as in the ^{48}Cr compound system reached in the scattering of ^{24}Mg on ^{24}Mg as well as the apparent absence of such structure in both the ^{58}Ni and ^{60}Ni compound systems. On the right of this figure are shown the potential energy contours, as calculated by Leander et al., for the L = 40 partial wave for these four compound systems, and it is at least suggestive that in the case

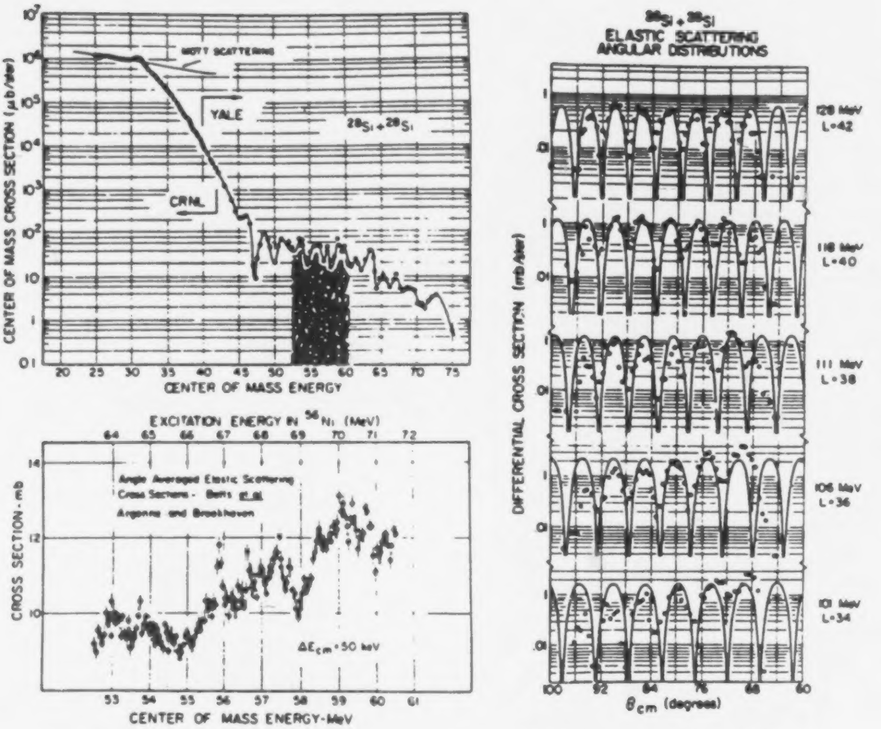


Figure 10: Aspects of the elastic scattering of $^{28}Si + ^{28}Si$. The upper left panel shows combined data from Yale and Chalk River from center-of-mass energies of 25 to 75 MeV. The shaded region is expanded in the lower left figure to show the fine structure corresponding to sharp states in the compound-nucleus ^{56}Ni. The panel on the right shows typical angular distributions measured at the indicated energies. When a particular partial wave becomes active in the scattering, the angular distribution can be reproduced with the square of the appropriate Legendre polynomial. The situation is particularly simple in the case of identical particles scattering because symmetry precludes the appearance of odd partial waves.

of ^{48}Cr and of ^{56}Ni secondary potential minima develop at very large deformation; the obvious suggestion—although it is not yet proven—is that the resonances correspond to states in these very highly deformed potential minima. What are required to resolve these speculations are data on much heavier nuclear systems than have been studied thus far and, in these systems, at angular momentum much higher than have been studied in the lighter systems.

That molecular interactions of this general type may persist even to the heaviest nuclear systems is illustrated in Fig. 12 showing work of Greenberg and his collaborators at GSI in West Germany. Originally these studies were stimulated by the suggestion of Greiner and his collaborators that, in the supercritical Coulomb fields attained during nuclear collisions with a combined atomic number in excess of 170, spontaneous ionization of the Dirac vacuum becomes possible. What was unexpected in the early measurements was the appearance in many of these supercritical systems of sharp positron lines superimposed on the anticipated positron spectrum, as shown in the upper left panel of this figure. In order to obtain an adequately long supercritical lifetime to correspond to the width of this positron peak, it has been suggested that, in a very small fraction of the collisions, long-lived molecular states may be formed, and the calculations thus far suggest that molecular binding is more probable in the nose-to-nose configuration labeled "Yukawa" than in the perhaps more obvious configuration labeled "proximity."

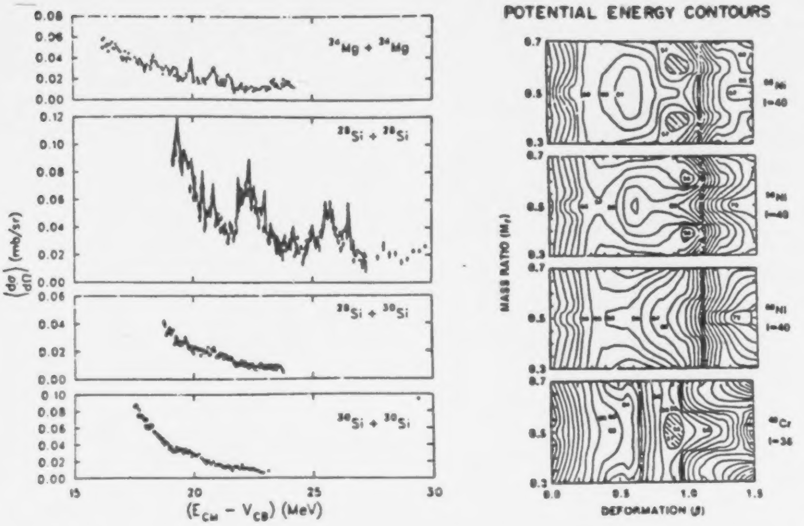


Figure 11: The left panel shows excitation functions obtained by Betts and his collaborators at the Argonne National Laboratory, while the right panel shows potential energy contours calculated by Leander et al. It is striking to note that in the case of ^{48}Cr and of ^{56}Ni, where the excitation functions show sharp structure, the potential energy contours show the existence of large deformation secondary minima in the potential surfaces, and the suggestion is that the resonance states correspond to quantum excitations in these large deformation minima.

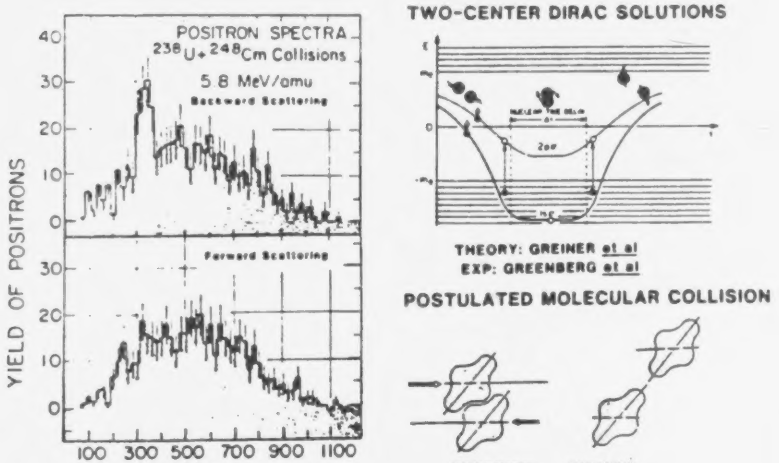
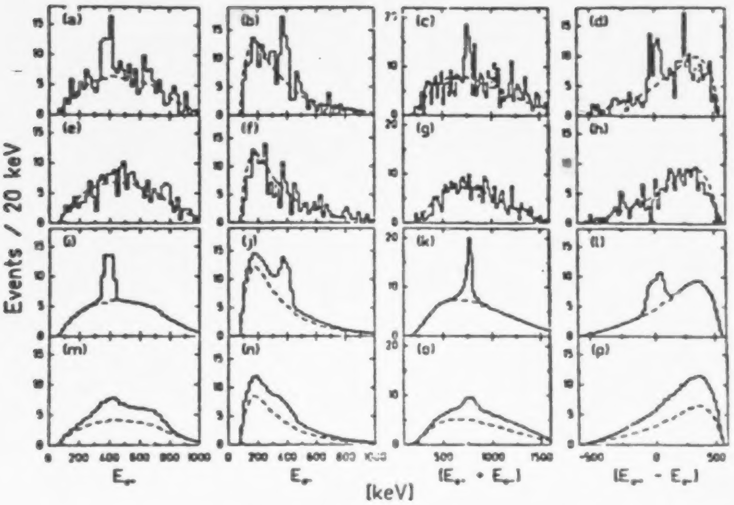


Figure 12: On the left are shown positron spectra taken in the upper panel in coincidence with backward scattered uranium ions and in the lower panel in coincidence with forward scattered uranium ions. The sharp positron lines superimposed on the continuous spectrum is quite obvious in the upper panel. On the upper right is shown the Dirac diagram for a supercritical nuclear scattering system and the nuclear time delay, corresponding to the sharp positron spike. is assumed to result from the formation of a transient molecular complex in the nuclear scattering of U on Cm. Preliminary calculations have demonstrated that the probability of molecular binding in the collision is greater in the case of a nose-to-nose collision, labeled here as Yukawa, than in the nestled case labeled here as proximity.



(a)-(h) : Projections of the experimental data

(i)-(l) Monte Carlo calculations assuming two-body decay of a neutral particle

(m)-(p) Monte Carlo calculations assuming internal pair conversion of a nuclear state

DATA OF COWAN et al. P.R.L. 56 444 (1986)

Figure 13: Electron positron coincidence events measured in U + Cm collisions together with Monte Carlo predictions for the projections of the experimental data shown here. In each case the dashed line drawn through the data and through the Monte Carlo predictions represents the dynamic positron background expected.

The experimental situation has recently become much more complex, as shown in Fig. 13, in that it has been demonstrated in a very difficult series of measurements that the positron lines occur in coincidence with electron lines of comparable energy. In the panels of Fig. 13, the dashed curves represent the dynamic background, normalized to the number of coincidence events, while the solid curves in the lower eight panels are Monte Carlo calculations based on the indicated assumptions. Although these data provide a tantalizing indication of a possible new neutral particle coupled to the electromagnetic field, no one has yet succeeded in coming forward with a particle having the necessary properties to explain these data while at the same time missing detection in earlier high-precision measurements on simple electromagnetic systems.

Whatever the ultimate explanation of these data may be, it seems clear that it will involve exciting new physics, and much of the present conference is of course devoted to attempting to determine what that physics might be.

SYMMETRIES IN NUCLEI

Symmetries in nuclei fall into three broad classes, as shown in Fig. 14. The geometric symmetries were first enunciated explicitly by A. Bohr in 1952. The kinematic symmetries are the fundamental ones usually characterized by P, C and T as well as Lorentz invariance. All of these date from the 1930s as indeed does the first of the dynamic symmetries, that of isospin, represented mathematically by the group U(2) and the supermultiplet theory of Wigner basic to alpha-particle models of the nucleus and governed by the group U(4). The isobaric mass

SYMMETRIES IN NUCLEI

A. Geometric Symmetries

(i) Axis of rotational symmetry in deformed nuclei Bohr(1952)
(ii) Planes of reflection symmetry in deformed nuclei Bohr(1952)

B. Kinematic Symmetries

(i) Parity (P)
(ii) Charge Conjugation (C)
(iii) Time Reversal Invariance (T)
(iv) Lorentz Invariance

C. Dynamic Symmetries

(i) Isospin U (2) Heisenberg (1932)
(ii) Supermultiplets U (4) Wigner(1936)
(iii) Isobaric Mass Formulae Garvey and Kelson (1969)
(iv) Harmonic Oscillator Symmetries U (3) Elliott (1958)
(v) Interacting Boson Structure Model

$$\begin{tikzcd} & U(5)\supset O(5)\supset O(3)\supset O(2) \\ U(6) \arrow[ur] \arrow[r] \arrow[dr] & U(3)\supset O(3)\supset O(2) \\ & O(6)\supset O(5)\supset O(3)\supset O(2) \end{tikzcd}$$

Iachello, Arima, Taimi (1974)

(vi) Algebraic Model For Scattering Iachello (1981)

$$\begin{tikzcd} & O(4)\supset O(3)\supset O(2) \\ U(4) \arrow[ur] \arrow[dr] & \\ & U(3)\supset O(3)\supset O(2) \end{tikzcd}$$

(vii) Supersymmetries

(a) Kinematic Weiss-Zumino (1974)
(b) Dynamic Bars-Iachello-Nambu (1980)

Figure 14: A compilation of the geometric kinematic and dynamic symmetries found in the nuclear many-body system.

expressions of Garvey and Kelson also correspond to a dynamic symmetry but one based on algebraic identities involving the nucleon-nucleon interactions. The U(3) harmonic oscillator symmetries introduced by Elliott in 1958 arose from the observation by Paul that shell and collective models of nuclei such as ^{19}F agreed with one another more closely than did either with experiment. More recently, the interacting boson model of Iachello, Arima and Talmi, dating from 1974, is governed by the group U(6) describing the behavior of postulated s and d bosons, whereas the algebraic model for scattering and indeed for binary cluster configurations, introduced by Iachello in 1981, is based on the U(4) group.

Finally, as indicated in Fig. 14, we have the two supersymmetries, the kinematic one introduced by Weiss and Zumino in 1974 in their work on supergravity and the dynamic one introduced by Bars, Iachello and Nambu in 1980 in their work on nuclear phenomena.

All these symmetries have played central roles in making possible the correlation and understanding of vast masses of nuclear data and indeed data in a great many physical systems. Within the past few years, however, the introduction of dynamic symmetries into the study of nuclear structure, with its characteristic replacement of the geometric techniques represented by the insertion of a model potential into a Schrodinger equation with subsequent solution for the model eigenvalues and eigenfunctions with an algebraic approach based on the above mentioned groups, has had revolutionary consequences. As illustrated in Fig. 15,

SYMMETRIES IN NUCLEI - I

Group Decomposition

$$\begin{array}{lll} & \nearrow U(5)\supset O(5)\supset O(3)\supset O(2). & (I)\\ U(6) & \rightarrow SU(3)\supset O(3)\supset O(2). & (II)\\ & \searrow O(6)\supset O(5)\supset O(3)\supset O(2). & (III)\end{array}$$

Quantum Numbers

$$\begin{array}{ccccccccc} U(6) & \supset & O(6) & \supset & O(5) & \supset & O(3) & \supset & O(2)\\ \downarrow & & \downarrow & & \downarrow & & \downarrow & & \downarrow\\ N & & \sigma & & \tau & (\nu_\Delta) & L & & M_L \end{array}$$

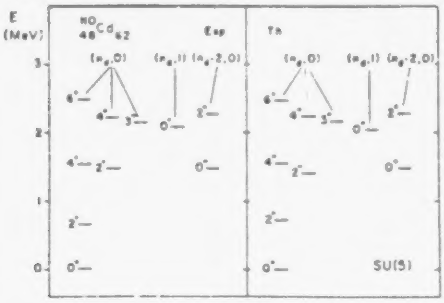
Mass Formulae

$$E^{(I)}(N, n_d, v, n_\Delta, L, M_L) = E_0^{(I)} + \varepsilon n_d + \alpha n_d(n_d + 4) + \beta v(v + 3) + \gamma L(L + 1).$$

$$E^{(II)}(N, \lambda, \mu, K, L, M_L) = E_0^{(II)} + \kappa(\lambda^2 + \mu^2 + \lambda\mu + 3\lambda + 3\mu) + \kappa' L(L + 1).$$

$$E^{(III)}(N, \sigma, \tau, \nu_\Delta, L, M_L) = E_0^{(III)} + A\sigma(\sigma + 4) + B\tau(\tau + 3) + CL(L + 1).$$

Vibrator Spectra



Rotor Spectra

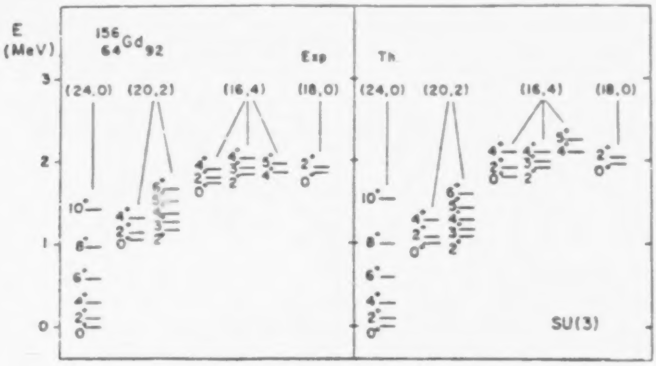
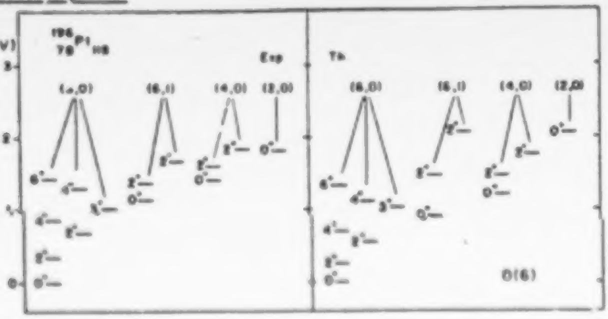
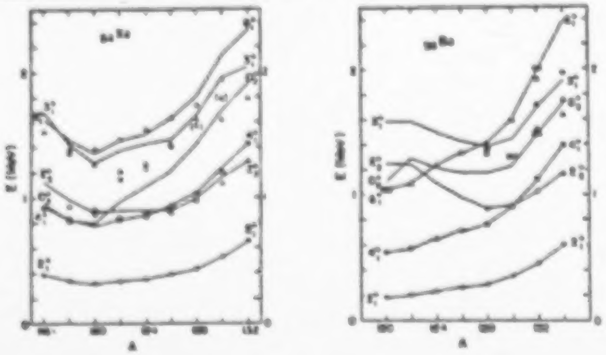


Figure 15: The upper part of this figure shows the decomposition of the U(6) group governing the interacting boson model for nuclear structure. Also shown are the quantum numbers appropriate to the chain and the mass formulae which result from the Casimir operators corresponding to the chain member. In the two lower panels, the excitation spectra corresponding to cases one and two are compared with experimental data on ^{110}Cd and ^{156}Gd respectively.

Triaxial Rotor Spectra



Evolution of Spectra in Even-Even Xe and Ba



Evolution of Spectra in Odd Xe

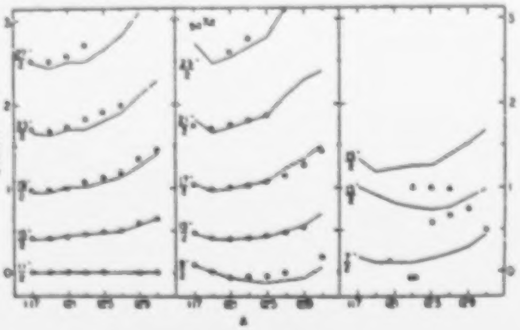


Figure 16: The upper panel compares theoretical predictions with experiment for the case of ^{196}Pt, the first nucleus to be identified as having the triaxial rotor configuration (case III of Fig. 15). The center panel compares the predictions of an interacting boson model with the excitation spectrum of the xenon and barium isotopes respectively, while the lower panel shows the evolution of spectra in odd xenon isotopes and compares the IBA predictions with the experimental data where available.

the U(6) group has only three decomposition chains which contain the O(3) group, a necessary condition for the resulting eigenfunctions to have angular momentum as a good quantum number. The quantum numbers appropriate to the various groups are as shown in this figure, and inserting the Casimir operators for the appropriate groups gives rise to the mass formulae shown for these three group chains. From the structure of these mass formulae, it is quickly obvious that the chains correspond, respectively, to an harmonic oscillator, to an axial rotor and to a triaxial rotor, respectively, each with characteristic spectra, and the lower two panels in Fig. 15 and the upper one in Fig. 16 show the now typical success that this model enjoys in reproducing experimental data.

Much more important, however, than the reproduction of these spectra for nuclei in regions where the three above mentioned models have long enjoyed considerable success, the interacting boson model has the tremendous advantage of being equally applicable in the transition regions where previously none of the models were valid. The central panel in Fig. 16 for example shows the IBA calculation of the spectra of the xenon and barium isotopes, respectively, as a function of neutron number, illustrating the transition from one of the limiting cases noted above to the other. The lower panel shows calculations on the evolution of spectra in the odd-mass xenon isotopes, again comparing IBA calculations with the experimental data now available.

DYNAMIC SUPERSYMMETRIES IN NUCLEI

To the extent that the success of the IBA makes it physically reasonable to consider even-even nuclei as consisting of well-defined bosons and thus as bosons

POSSIBLE SUPERSYMMETRY IN NUCLEI - I

A $j = 3/2$ VALENCE NUCLEON COUPLED TO AN O(6) TRIAXIAL ROTOR CORE

SUPERGROUP DECOMPOSITION

$$\begin{array}{ccccccccccccccc} U(6/4) & \supset & U^{(B)}(6) & \otimes & U^{(F)}(4) & \supset & O^{(B)}(6) \otimes SU^{(F)}(4) & \supset & Spin(6) & \supset & Spin(5) & \supset & Spin(3) & \supset & Spin(2) \\ \downarrow & & \downarrow & & \downarrow & & \downarrow & & \downarrow & & \downarrow & & \downarrow & & \downarrow \\ \mathcal{N} & & N & & M & & \Sigma & & \sigma_1, \sigma_2, \sigma_3 & & \tau_1, \tau_2 (\nu_\Delta) & & J & & M_J \end{array}$$

MASS FORMULA

$$\begin{aligned} E(\mathcal{N}, N, M, \Sigma, \sigma_1, \sigma_2, \sigma_3, \tau_1, \tau_2, \nu_\Delta, J, M_J) = \mathcal{E}_0 + \mathcal{E}_1 N + \mathcal{E}_2 N^2 + A\Sigma(\Sigma + 4) \\ + A'\left[\sigma_1(\sigma_1 + 4) + \sigma_2(\sigma_2 + 2) + \sigma_3^2\right] \\ + B\left[\tau_1(\tau_1 + 3) + \tau_2(\tau_2 + 1)\right] + CJ(J + 1) \end{aligned}$$

SUPERMULTIPLETS

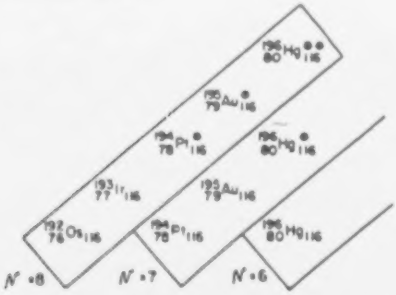
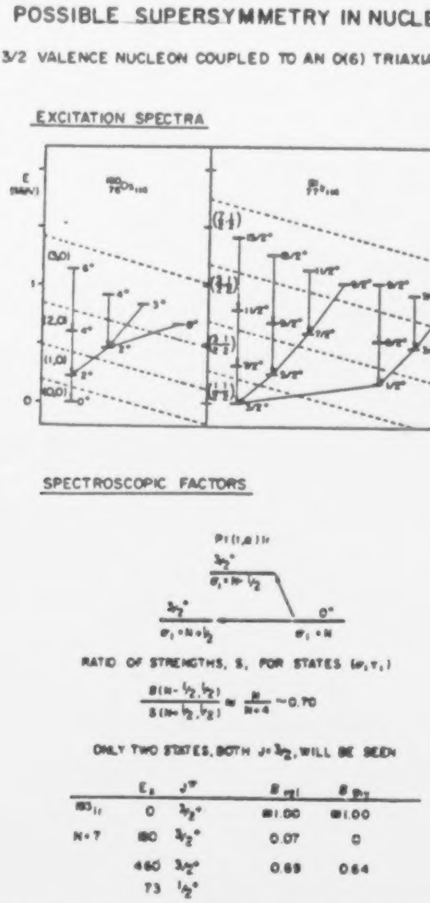


Figure 17: The super group decomposition corresponding to a $j = 3/2$ valence nucleon coupled to a O(6) triaxial core leads to the indicated mass formula, and the lower panel shows the region around ^{193}Ir where supersymmetric behavior has been most clearly identified.

themselves, odd-mass nuclei with a single valence nucleon should be describable by a dynamic supersymmetry treating fermions and bosons on an equal footing. Figure 17 shows the case of a j = 3/2 valence nucleon coupled to an O(6) triaxial rotor core, illustrating the decomposition of the relevant supergroup U(6/4) and the corresponding mass formula.

Whereas dynamic symmetries lead to families of quantum states within a single nucleus, dynamic supersymmetries lead to supermultiplets of states in adjacent nuclei, as well as to relations between the ground state masses of these nuclei, electromagnetic transitions within them and spectroscopic factors for transfer reactions linking them. The supersymmetries are characterized by the primary quantum number $\mathcal{N}$, and in the lower panel of this figure, I show parts of three of the supermultiplets. In Fig. 18, taken from work of Cizewski et al., I show the predicted deexcitation behavior of even- and odd-mass nuclei in the supermultiplet which reproduces, with high accuracy, the experimental observations, and in the lower panel I show that the model calculations for single proton pickup reactions also reproduce the experimental data quite well.



POSSIBLE SUPERSYMMETRY IN NUCLEI - II

A j=3/2 VALENCE NUCLEON COUPLED TO AN O(6) TRIAXIAL ROTOR CORE

EXCITATION SPECTRA

E (MeV)
1
0
(3,0)
(2,0)
(1,0)
(0,0)
6+
4+
3+
2+
0+
$(\frac{7}{2}\frac{1}{2})$
$(\frac{5}{2}\frac{1}{2})$
$(\frac{3}{2}\frac{1}{2})$
$(\frac{1}{2}\frac{1}{2})$
15/2+
13/2+
11/2+
9/2+
7/2+
5/2+
3/2+
1/2+
Th

SPECTROSCOPIC FACTORS

RATIO OF STRENGTHS, S, FOR STATES (σ1, τ1)

$$\frac{S(N-\frac{1}{2},\frac{1}{2})}{S(N+\frac{1}{2},\frac{1}{2})} = \frac{N}{N+4} \sim 0.70$$

ONLY TWO STATES, BOTH J=3/2, WILL BE SEEN

	E_x	J^π	S_{exp}	S_{th}
^{193}Ir	0	3/2+	≡1.00	≡1.00
N=7	180	3/2+	0.07	0
	460	3/2+	0.69	0.64
	73	1/2+		

Figure 18: The upper panel shows predicted supersymmetric deexcitation patterns for even- and odd-mass nuclei in the iridium region. These predicted patterns are in excellent agreement with the experimental data. The lower panel shows a comparison of the spectroscopic factors obtained experimentally and predicted from a supersymmetric model for the case of proton pickup on platinum targets.

It has been established that the supersymmetry model works remarkably well in the vicinity of ^{190}Ir. Furthermore, it has been possible to show that as the supersymmetry is broken in moving away from ^{193}Ir, reproduction of the experimental observations can be regained by varying only a single parameter—namely, the strength of the coupling of the valence fermion to the bosonic core. Obviously one of the major challenges now facing those studying nuclear structure is that of finding other areas of the periodic table where supersymmetric effects are equally apparent. Although the case has not yet been firmly made, there is growing evidence that such an area is to be found in the neutron deficient barium region.

DYNAMIC SYMMETRY IN NUCLEAR INTERACTIONS

Despite the success of the interacting boson model in reproducing the structure of nuclei i.e. the nuclear bound states, there has always been considerable question as to whether the group theoretical and algebraic approaches could be used to describe the unbounded wave functions encountered in nuclear scattering and other interactions. The first evidence that this might, in fact, be possible came from studies on the molecular resonances in the C + C system, as shown in Fig. 19. The first three of these resonances were discovered in the first measurements with the first tandem accelerator at the Chalk River Laboratories in 1959. Subsequent, more detailed studies at Yale, at Caltech and at Munster have finally given rise to some 39 discreet resonances in the region of the Coulomb barrier, as shown in the upper panel of this figure. With this complexity there seemed little hope of any simple explanation until a few years ago when Iachello recognized that the effective potential, which we had been using to try to model these nuclear molecular resonances, looked very much like a standard Morse potential and that furthermore any physical system describable by a Morse potential could equally well be described by a dynamic U(4) symmetry, leading to the analytic form for the eigenvalues shown in the lower panel. The value of the fitting parameter c appearing here is that appropriate to two touching carbon spheres, whereas the other three, D, a and b, were fitting to three of the very well-determined resonances, so that no further fitting parameters were available for the remaining 36 resonances. The rather remarkable result shown in the lower panel suggests that a U(4) description of these states is an entirely reasonble one and led to substantially increased insight into the mechanisms whereby these resonances occur.

Within the past year it has been recognized more generally that noncompact groups of the form SO(m,n) may have much broader applicability in the understanding of nuclear interactions. As shown in Fig. 20, Pauli had recognized in 1926 that nonrelativistic Coulomb scattering has a dynamic symmetry SO(3,1). More generally, in 1986, Alhassid **et al.** have demonstrated that once the appropriate dynamic symmetry can be established, it is possible to write down the pertinent S matrix elements analytically and further that the parameter m is the dimensionality of the problem, while n is the number of parameters required to establish the interaction under study.

Figure 21 illustrates the success of this approach in some preliminary applications that we have undertaken at Yale. The data here are those of Korotky **et al.** on the ^{13}C + ^{13}C system, and the dashed curve is the best fit that we were able to obtain after substantial optical model searches with six parameters available. The solid curve, on the other hand, is that obtained using the scattering matrix elements appropriate to an SO(3,2) symmetry with the complex parameter ν chosen as indicated (i.e. two-fitting parameters). Equivalent success has been obtained in reproducing heavy-ion elastic angular distributions.

As indicated in Fig. 20, the S matrix elements used here quite naturally factor, and we are hoping that it may be possible to apply this formalism to more complex interactions such as inelastic scattering, transfer reactions and so on by

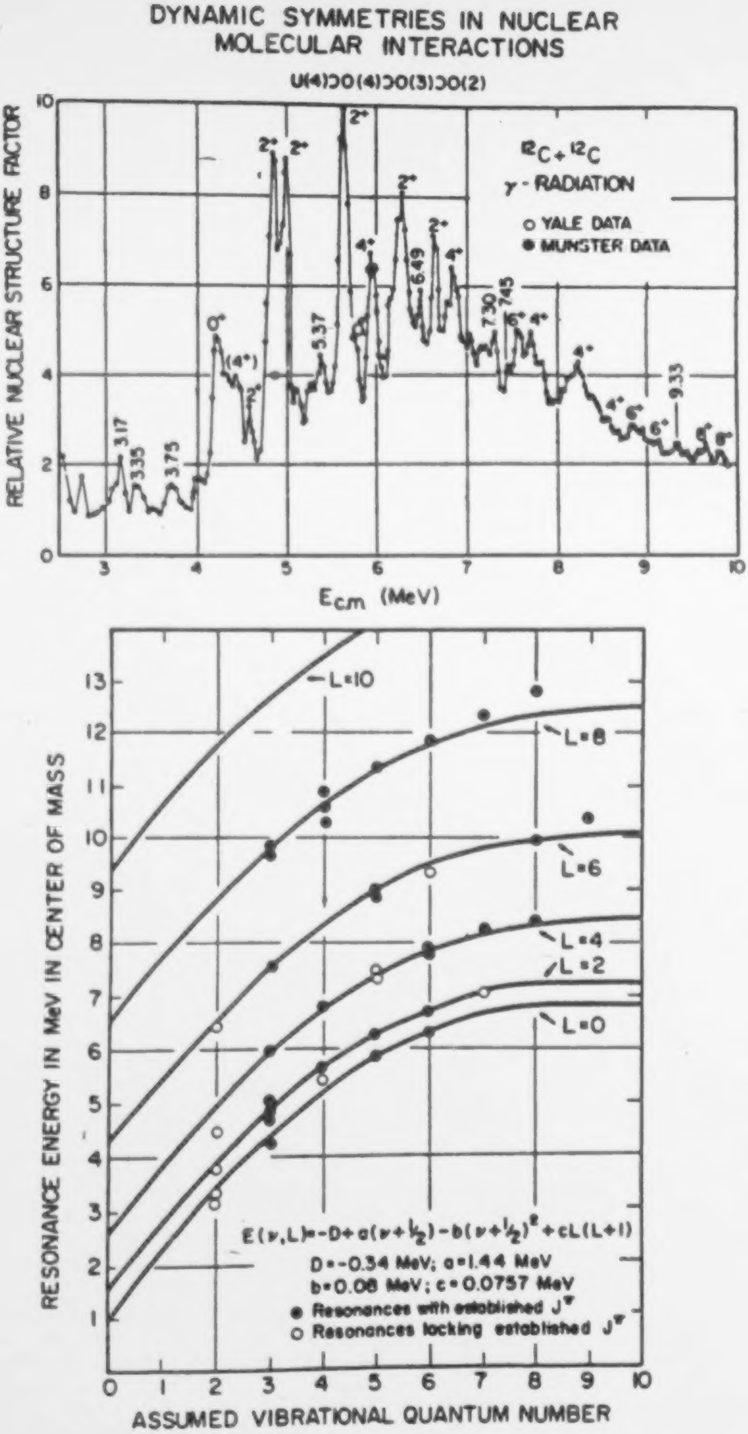
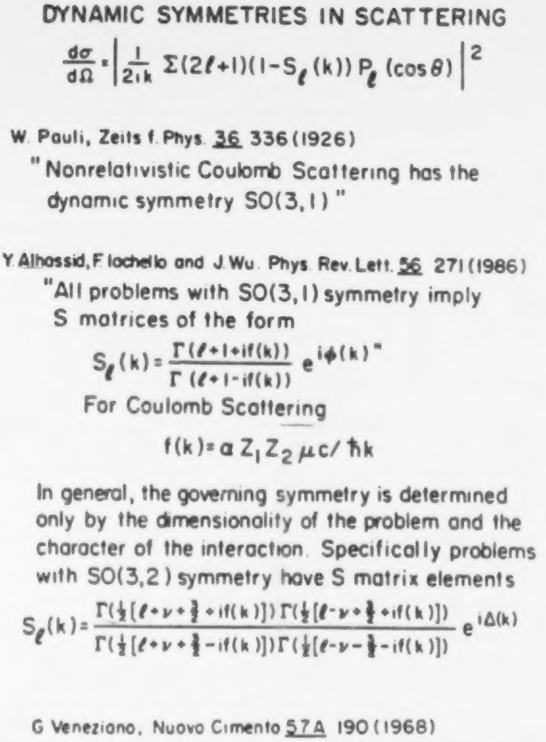


Figure 19: The upper panel shows the molecular resonances in the $^{12}C + ^{12}C$ scattering system in the region of the Coulomb barrier. The lower panel shows a fit to the indicated eigenvalue expression.



DYNAMIC SYMMETRIES IN SCATTERING

$$\frac{d\sigma}{d\Omega} = \left| \frac{1}{2ik} \Sigma(2\ell+1)(1-S_\ell(k))\, P_\ell(\cos\theta) \right|^2$$

W. Pauli, Zeits f. Phys. 36 336 (1926)

"Nonrelativistic Coulomb Scattering has the dynamic symmetry SO(3,1)"

Y. Alhassid, F. Iachello and J. Wu. Phys. Rev. Lett. 56 271 (1986)

"All problems with SO(3,1) symmetry imply S matrices of the form

$$S_\ell(k) = \frac{\Gamma(\ell+1+if(k))}{\Gamma(\ell+1-if(k))}\, e^{i\phi(k)}\text{"}$$

For Coulomb Scattering

$$f(k) = \alpha Z_1 Z_2 \mu c/\hbar k$$

In general, the governing symmetry is determined only by the dimensionality of the problem and the character of the interaction. Specifically problems with SO(3,2) symmetry have S matrix elements

$$S_\ell(k) = \frac{\Gamma(\frac{1}{2}[\ell+\nu+\frac{3}{2}+if(k)])\,\Gamma(\frac{1}{2}[\ell-\nu+\frac{3}{2}+if(k)])}{\Gamma(\frac{1}{2}[\ell+\nu+\frac{3}{2}-if(k)])\,\Gamma(\frac{1}{2}[\ell-\nu-\frac{3}{2}-if(k)])}\, e^{i\Delta(k)}$$

G Veneziano, Nuovo Cimento 57A 190 (1968)

Figure 20: The upper expression defines the scattering S-matrix elements for each orbital partial wave, while the lower part of the figure shows the S-matrix elements appropriate to the noncompact groups SO(3,1) and SO(3,2) respectively. This work in nuclear physics is closely related to that done in the late 1960s in elementary particle physics, as summarized for example by Veneziano in the indicated publication.

identifying the first factor with the entrance channel and the second with the exit channel using appropriately different parameters in the two cases. We are just beginning these studies at the present time, and what is urgently needed is a much more extensive body of experimental data on heavier systems than have been studied thus far and to higher energies than have been available thus far in all systems. To the extent that these studies are successful, this algebraic approach to the understanding of nuclear interactions can at least in principle have as great an impact on the understanding of these interactions as the interacting boson model has had on the understanding of nuclear structure. This is a very exciting possibility and one that will occupy a great many laboratories in the coming few years.

NEW FACILITIES IN LOW-ENERGY NUCLEAR PHYSICS

All of the topics that I have discussed thus far are within the realm of what is now called "classical nuclear physics" i.e. that accessible to tandem Van de

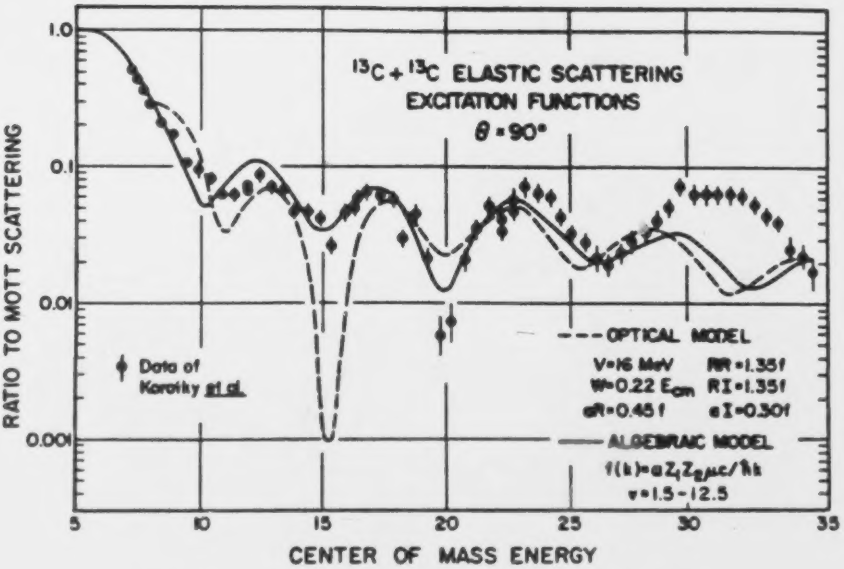


Figure 21: A comparison of the fits attained with an optical model and with the algebraic model of Figure 20 to data of Korotky et al. on the $^{13}C + ^{13}C$ 90° elastic scattering excitation function.

Graaffs, cyclotrons, linear accelerators and appropriate combinations of all three, accelerating essentially all particles from protons to uranium nuclei. As is obvious, there remains an enormous open frontier available for study with these facilities, and fortunately, a series of new and very powerful machines are just now either coming into operation or will come into operation within the next year. Included here are the tandem-linear accelerator combinations typified by the ATLAS unit at the Argonne National Laboratories, the double superconducting cyclotron system at the Michigan State University, the large tandem electrostatic accelerators at the Oak Ridge and Daresbury National Laboratories and appropriate combinations in a great many laboratories around the world. In Fig. 22, I illustrate the conversion project that is something more than half completed in my own Laboratory at Yale where we are replacing the first of the MP class tandem accelerators—which operated originally at 10 MV on terminal—with the first of the much larger ESTU tandems which we anticipate to operate somewhere between 22 and 25 MV on terminal.

STUDIES WITH ELECTRON ACCELERATORS

Until very recently, work with electron accelerators characteristically suffered from low energy resolution and serious background problems, so that it was extremely difficult if not impossible to isolate individual quantum states in the nuclei under study. That this is no longer the case is illustrated in striking fashion by Fig. 23 taken from recent work from the Netherlands. Here, inelastic electron scattering, with the removal of a proton from ^{208}Pb to leave a residual ^{207}Tl nucleus, is shown at three different momentum transfers. Clearly, the resolution is more than adequate to separate the proton groups coming from specific shell-model states in the lead nucleus.

Although highly complementary to work done with the lower-energy tandem accelerators and cyclotrons, these data are still restricted to phenomena in the nuclear surface. There has long been considerable question as to whether the simple shell model concepts apply deep in the nuclear interior i.e. do nucleons

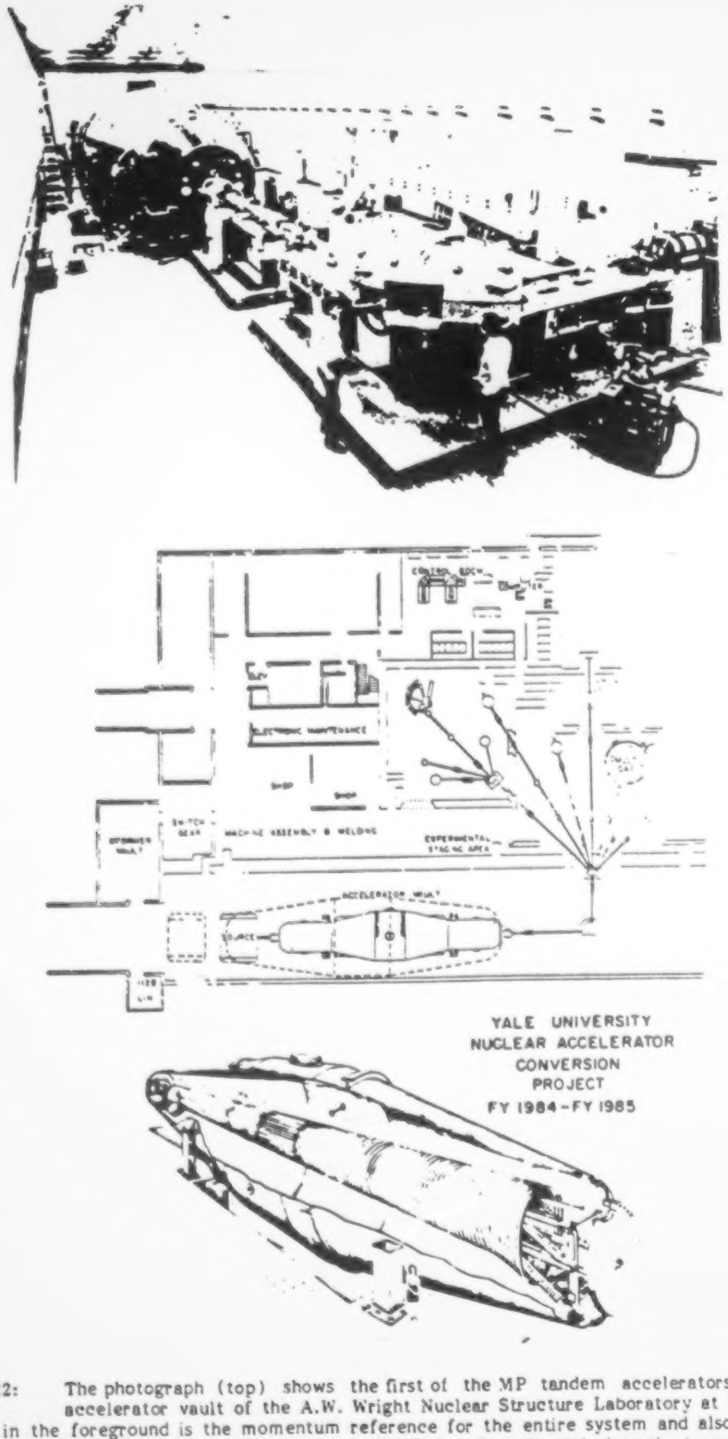

CONTROL ROOM
ELECTRONIC MAINTENANCE
SHOP
SHOP
SWITCH GEAR
MACHINE ASSEMBLY & WELDING
EXPERIMENTAL STAGING AREA
ACCELERATOR VAULT
SOURCE
YALE UNIVERSITY
NUCLEAR ACCELERATOR
CONVERSION
PROJECT
FY 1984-FY 1985

Figure 22: The photograph (top) shows the first of the MP tandem accelerators in the accelerator vault of the A.W. Wright Nuclear Structure Laboratory at Yale. The magnet in the foreground is the momentum reference for the entire system and also serves to direct the accelerated beams through the heavy shielded wall on the right into the target areas. A schematic diagram of the ground floor layout of the Laboratory is given (below) and the new ESTU accelerator now under construction, is shown in dashed outline superimposed on the MP accelerator. A cutaway view of the ESTU machine is shown at the lower right.

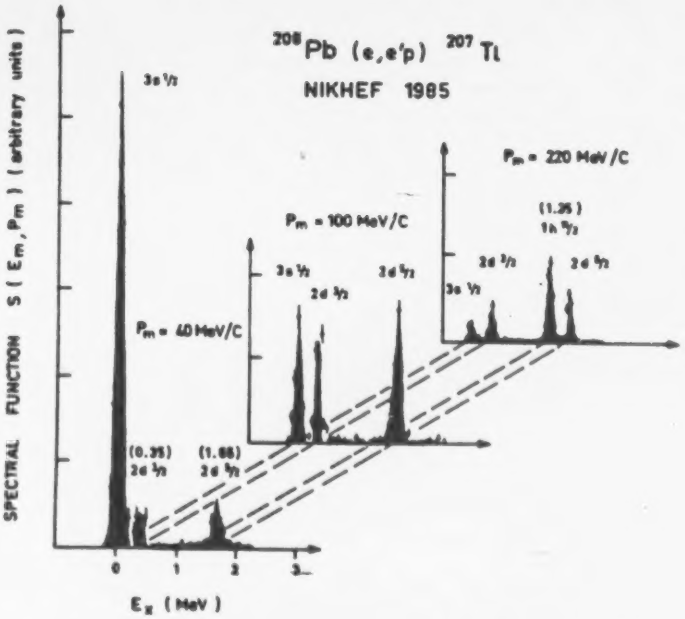


Figure 23: Inelastic electron scattering on ^{208}Pb with removal of protons from the indicated shell-model states. The experimental results are shown for three different momentum transfers showing the characteristic behavior of the different shell-model orbitals as a function of momentum transfer.

behave when they are in the central region of a heavy nucleus as they would in a free state or as they do on the surface of nuclei. Figure 24, taken from work of Frois and his collaborators at Saclay answers this question in rather dramatic fashion. Scattering high-energy electrons on both ^{206}Pb and ^{205}Tl, the difference between the two situations can be attributed to the presence of the additional 3s proton in ^{206}Pb, and subtraction of the pertinent data leads to the 3s wave function shown at the bottom of this figure. As is clear, this is a classic 3s wave function, demonstrating once and for all that at least as probed by high-energy electrons, the shell model does provide an excellent representation of nucleon behavior, even in the center of heavy nuclei.

Figure 25 is an outline plan of the 750 MeV electron linac facility at the Bates Laboratory at MIT; the MIT group currently has a proposal under consideration to extend the energy of this machine to 1 GeV while retaining the energy resolution typified by the data of Figs. 24 and 23.

There has, in fact, been substantial and growing pressure from the international nuclear science community for electron accelerator facilities with higher duty factor and higher energy while still retaining excellent energy resolution. One of the most striking data leading to this increased interest is the so-called EMC effect first reported by the European Muon Collaboration group from studies on the inelastic scattering of high-energy muons on nuclei. Plotted in Fig. 26 are their results, together with older data on the similar inelastic scattering of high-energy electrons measured at SLAC—data which had not been analyzed until publication of the EMC results. What is shown here is the ratio of the form factors for high-energy muon and electron scattering on nucleons in an iron target and in a deuterium target. Conventional wisdom had always been that the specific target would make no difference in these studies any more than would the chemical composition of a standard target used in conventional nuclear physics. The obvious departure of this ratio from 1, as a function of the Bjorken scaling parameter X, has been interpreted in a variety of ways to indicate at least partial deconfinement of the quarks in the heavy nuclear systems. I shall return to this matter later, since there is considerable disagreement as to the proper explanation of these data. Whatever that may be, however, they have stimulated substantial interest in the possibility of using high-energy electron beams to scan the transition from normal hadronic matter to that where the underlying quarks are beginning to act as free agents.

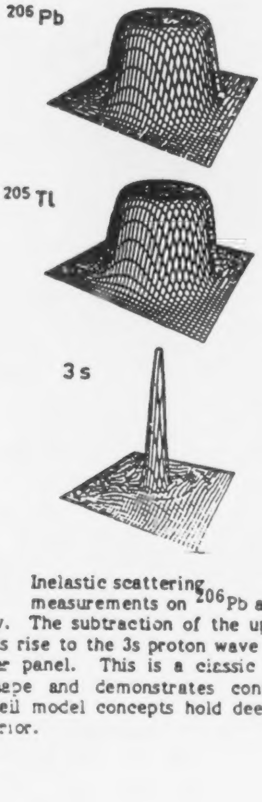


Figure 24: Inelastic scattering measurements on ^{206}Pb and ^{205}Tl from Saclay. The subtraction of the upper two figures gives rise to the 3s proton wave function in the lower panel. This is a classic 3s wave function shape and demonstrates conclusively that the shell model concepts hold deep in the nuclear interior.

Figure 27, illustrating the scattering of electrons from protons, is useful in illustrating this transition from hadronic to quark matter and in demonstrating what energy electrons are required to study the transition. What is plotted here is the scattering form factor as a function of energy loss and of scaling parameter. At low energies, the scattering is simply from the nucleons in their ground state; but with higher energy, the nucleons themselves are excited to the delta resonance and then to the various N* resonances, so that the nuclear system being studied changes from one comprised of nucleons to one where a number of the nucleons are themselves in excited configurations. Moving higher in energy, the current evidence suggests that the nucleons begin to leak quarks and on occasion to form six quark entities, so that in effect the nucleons gradually melt into a quark-gluon

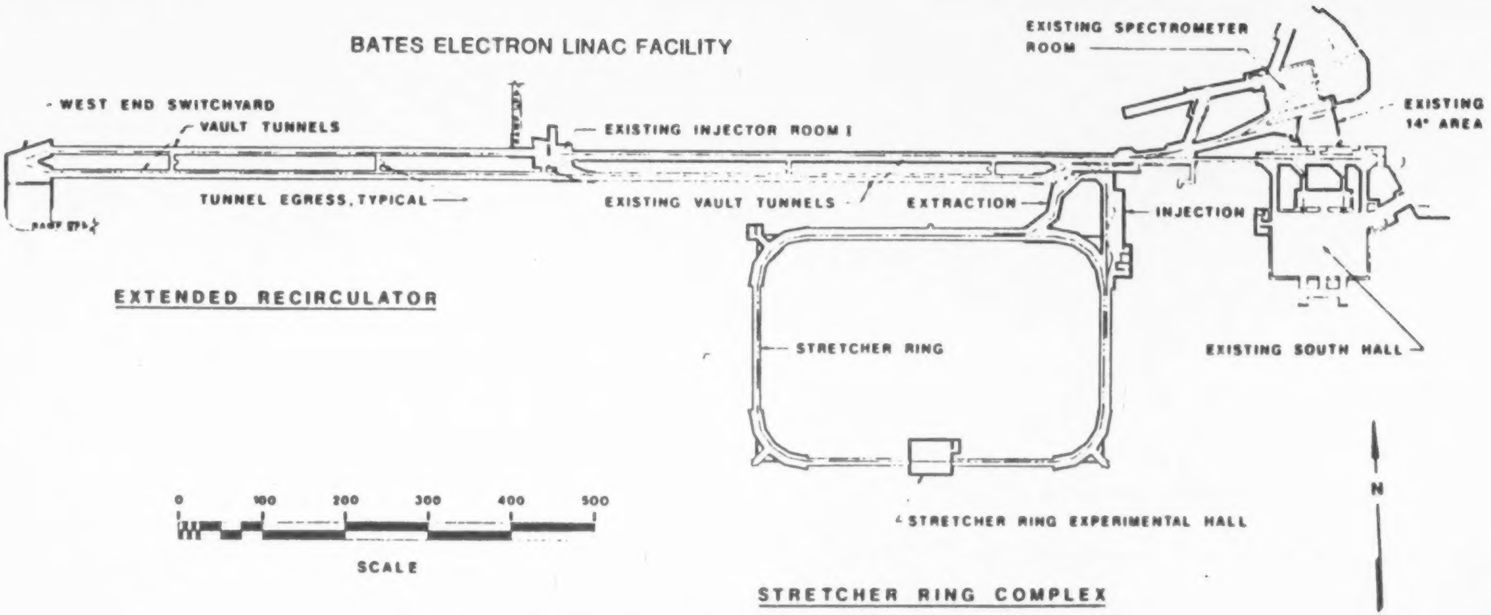

BATES ELECTRON LINAC FACILITY
WEST END SWITCHYARD
VAULT TUNNELS
TUNNEL EGRESS, TYPICAL
EXISTING INJECTOR ROOM I
EXISTING VAULT TUNNELS
EXTRACTION
INJECTION
EXISTING SPECTROMETER ROOM
EXISTING 14° AREA
EXISTING SOUTH HALL
EXTENDED RECIRCULATOR
STRETCHER RING
STRETCHER RING EXPERIMENTAL HALL
STRETCHER RING COMPLEX
N
0
100
200
300
400
500
SCALE

Figure 25: The Bates Electron Linac Facility at the Massachusetts Institute of Technology. Currently this facility operates at 750 MeV without either the extended recirculator or the stretcher ring complex. These are both parts of a proposed upgrading of the facility to provide 1 GeV operation with higher duty cycle.

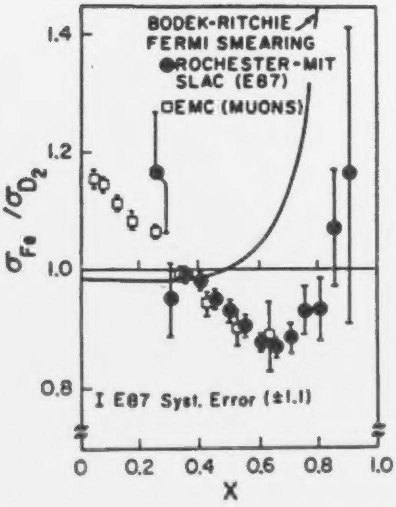


Figure 26: The EMC effect as measured at CERN and at SLAC. The solid curve shows the predicted behavior taking into account the internal Fermi momentum in the nuclei involved. What is plotted here is a ratio of the inelastic scattering form factors for iron and deuterium against the Bjorken scaling parameter.

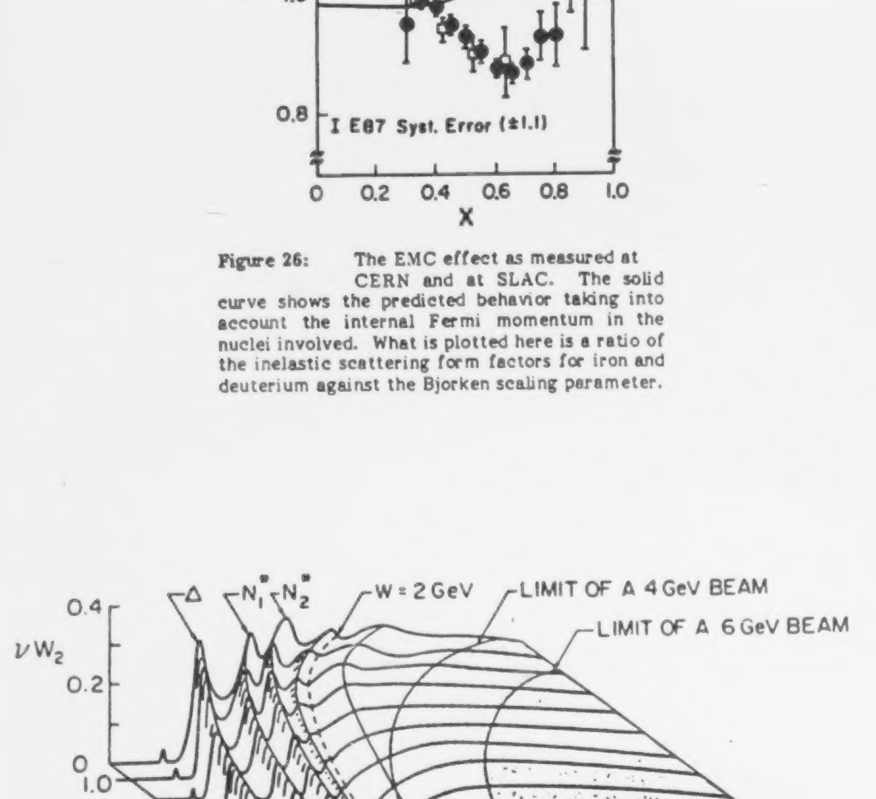


Figure 27: Scattering of electrons from nucleons plotted as form factor against energy loss and scaling parameter. The curves labeled 2,4 and 6 GeV define the right boundary of the regime available to experimental study with such a facility.

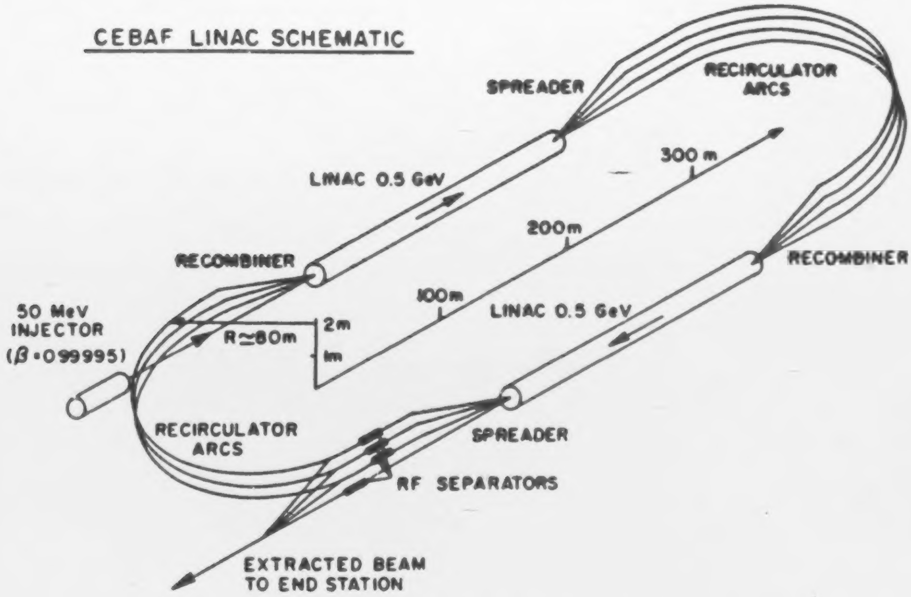


Figure 28: A schematic layout of the planned CEBAF electron accelerator facility. Two 0.5 GeV superconducting linacs will be arranged as shown, and spreaders make it possible to extract the beam at several different energies below the maximum value. The recirculator arcs have been designed so that they can encompass additional magnetic dipoles to increase the maximum energy to 16 GeV at some future time.

plasma. It must be emphasized however that complete conversion into the quark-gluon plasma cannot be expected at energies less than many tens of GeV. As shown in this figure, with a 2 GeV accelerator it will not be possible to get much beyond the situation where the nucleons are excited. With a 4 GeV beam, it becomes possible to at least begin to probe the quark domain, and with a 6 GeV beam a much more solid foothold can be expected in the scaling regime, although again it must be emphasized that even with 6 GeV, one would be nowhere near a regime where quantum chromodynamics, for example, could be used in perturbative fashion.

Obviously, this transition region from hadronic to quark matter will be an exceedingly complex one and one that will be very difficult to analyze from a theoretical point of view. Compensating for this difficulty, however, is the fact that the physics will be correspondingly very interesting.

In the U.S., the decision has already been made to proceed with the construction of a 100% duty cycle accelerator with an initial guaranteed maximum electron energy of 4 GeV. This so-called Continuous Electron Beam Acclerator Facility (CEBAF) is shown schematically in Fig. 28. Recent progress in the design and fabrication of superconducting linear accelerator cavities has been such that the design of this facility is now based on their use. The recirculator arcs have been designed so that if, and when, the research program makes it desirable the maximum energy of the machine can be increased from 4 to 16 GeV through the addition of further sections to the two linacs and additional dipole magnets to the recirculator arcs.

The CEBAF facility is now approved for construction beginning during 1987. Figure 29, which plots the duty factor versus the maximum beam energy for a number of the world's electron accelerator facilities demonstrates the unique position that it will be occupy. A very active scientific program has already been

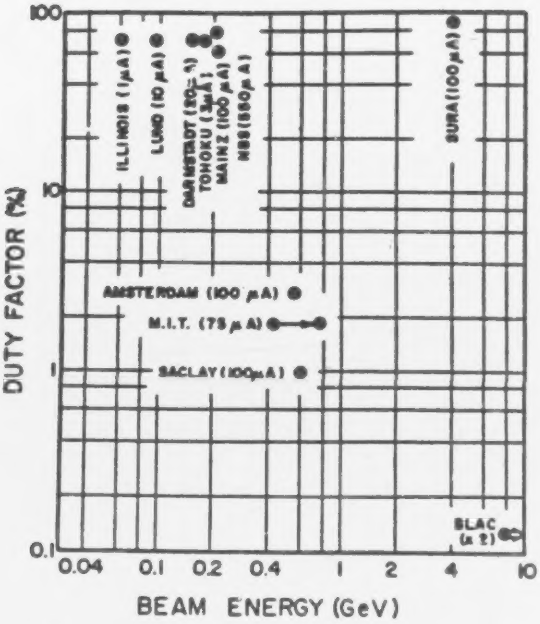


Figure 29: A comparison of the world's major electron accelerator facilities plotting duty factor against maximum beam energy.

developed for this facility as soon as it becomes functional in 1991. Included in this is the study of the role of mesons, of excited baryons and of quarks in nuclei; of the strong force, including nonperturbative features of quantum chromodynamics; of the effect of the nuclear medium on nucleon structure and on quark interactions. Among the advantages that electrons have in these studies are first, that the electromagnetic interaction is extremely well-understood (perturbative QED); the electrons probe the entire nuclear volume; and the energy loss and momentum transfer can be varied independently.

Before leaving electrons, however, it is also important to consider recent Saclay data, as shown in Fig. 30. These studies on the electrodisintegration of the deuteron should provide a strong cautionary note for those interested in probing quark phenomena in the nuclear domain. As is obvious from this figure, calculations which assume the deuteron to consist of only a neutron and protron (the impulse approximation) bear no resemblance to the experimental data whatever. What is truly remarkable is the degree to which the calculations reproduce the experimental results as soon as they include the presence of soft pion exchange in addition to the impulse approximation. Indeed, these calculations give an excellent reproduction of the experimental data down to distances of 0.2 Fm without invocation of any quark effects whatever. The fact that the solid curve here, which includes the effect of both rho meson exchange and nucleon excitation to the delta resonance makes so little change in the predicted cross section reflects the fact that the rho and delta contributions are essentially equal, of opposite sign, hence cancel.

It is essential to bear these results in mind, and not leap too quickly to the invocation of quark phenomena. This is a point that has been emphasized repeatedly by G.E. Brown and is a point well-taken. There has already been considerable literature pollution in attempts to see quark signatures in data which were entirely explicable in terms of more traditional nuclear physics.

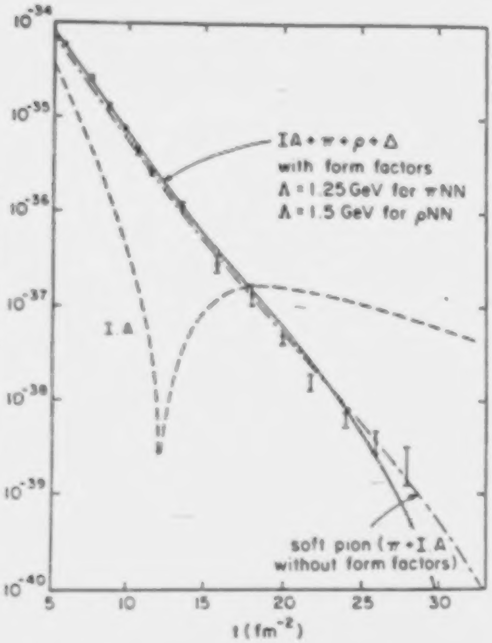


Figure 30: The cross section for electric disintegration of the deuteron, as measured at Saclay. The dashed curve labeled IA is that obtained from an impulse approximation calculation assuming the presence of only a neutron and a proton. The dot-dashed curve is that obtained in an impulse approximation calculation which also includes soft exchange pions: it provides a remarkable fit to the experimental data down to radii of 0.2 Fm. The solid curve includes additionally the effects of ρ meson exchange and excitation of the nucleons to the Δ resonance. The fact that this makes essentially no change in the prediction results from the fact that the ρ and Δ contributions are of essentially identical magnitude and opposite sign.

HEAVY-ION INTERACTIONS AT HIGH ENERGY

There is general agreement that if we are to see quark effects in unambiguous fashion and really probe the nuclear equation of state, we will do so in the simplest fashion using very high-energy heavy-ions.

Until this past year, however, there has been considerable uncertainty and ambiguity as to the character of these very high-energy heavy-ion interactions. As shown in Fig. 31, it was not at all clear whether the collisions were better described with hydrodynamic models wherein the nuclear matter was assumed to behave like an Euler fluid or by cascade models wherein the collision was assumed to proceed through a time ordered sequence of nucleon-nucleon collisions. The problem was primarily an experimental one in that it was extremely difficult to separate out the central collisions of greatest interest from the much more numerous peripheral ones, each having their characteristic observables as indicated in this figure. During the past year, studies by the joint LBL-GSI group, using the plastic ball detector at the Bevalac accelerator to unambiguously separate out central collisions, have obtained the data shown in Fig. 32. The striking feature of these

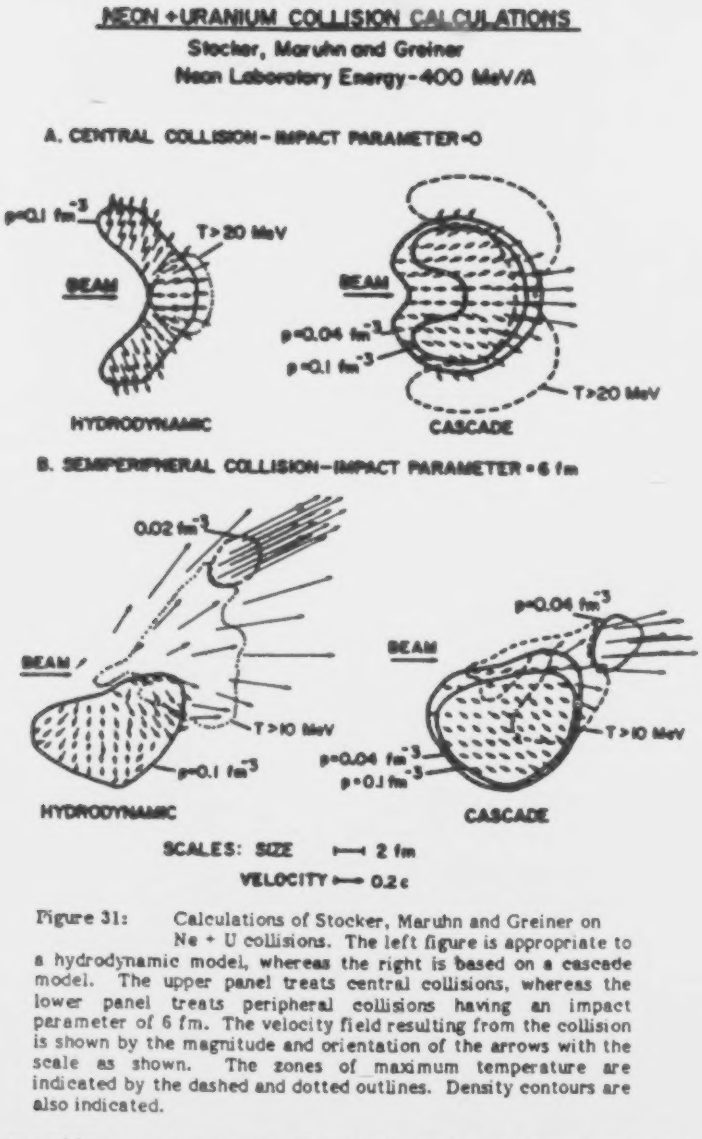

NEON + URANIUM COLLISION CALCULATIONS
Stocker, Maruhn and Greiner
Neon Laboratory Energy-400 MeV/A
A. CENTRAL COLLISION - IMPACT PARAMETER = 0
ρ=0.1 fm⁻³
T>20 MeV
BEAM
HYDRODYNAMIC
BEAM
ρ=0.04 fm⁻³
ρ=0.1 fm⁻³
T>20 MeV
CASCADE
B. SEMIPERIPHERAL COLLISION-IMPACT PARAMETER = 6 fm
0.02 fm⁻³
BEAM
T>10 MeV
ρ=0.1 fm⁻³
HYDRODYNAMIC
ρ=0.04 fm⁻³
BEAM
T>10 MeV
ρ=0.04 fm⁻³
ρ=0.1 fm⁻³
CASCADE
SCALES: SIZE ⊢ 2 fm
VELOCITY ⊢ 0.2 c

Figure 31: Calculations of Stocker, Maruhn and Greiner on Ne + U collisions. The left figure is appropriate to a hydrodynamic model, whereas the right is based on a cascade model. The upper panel treats central collisions, whereas the lower panel treats peripheral collisions having an impact parameter of 6 fm. The velocity field resulting from the collision is shown by the magnitude and orientation of the arrows with the scale as shown. The zones of maximum temperature are indicated by the dashed and dotted outlines. Density contours are also indicated.

data is the unambiguous appearance of hydrodynamic shock angles, particularly in moving from the Ca + Ca up to the much heavier Au + Au studies, thus demonstrating the physical reality of the hydrodynamic picture of heavy-ion collisions. This has the very important consequence that densities substantially higher than normal can be anticipated in the heavy-ion collision, whereas had a cascade model been the appropriate one, there would have been negligible compression.

Up to now essentially all our information on the behavior of heavy-ion collisions at very high energy has been obtained at the Dubna Synchrophasotron and the Berkeley Bevalac; the latter is shown in Fig. 33 with the beam path indicated from the Superhilac injector down the hillside to the former Bevatron proton synchrotron now used jointly as the Bevalac to obtain something over 2 GeV per nucleon for all ions up to and including uranium. A modern copy of this facility is currently under construction at GSI in Darmstadt, West Germany, and the Lawrence

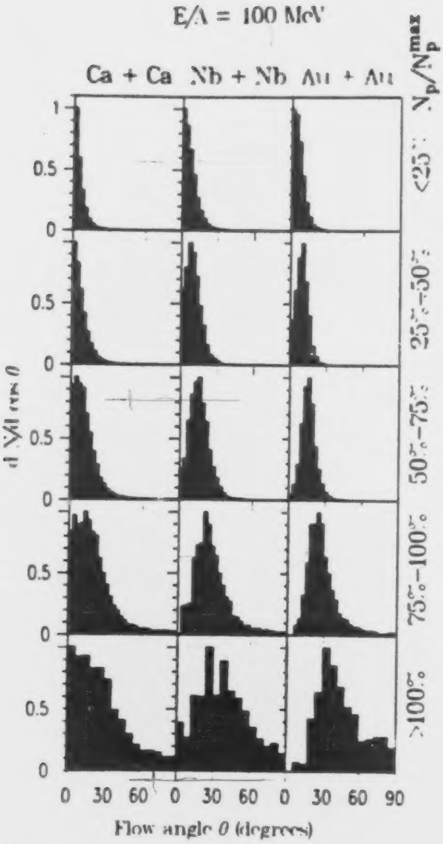


Figure 32: Results from identical particle collisions at 100 MeV per nucleon measured at the Berkeley Bevalac for Ca, Nb and Au. What is plotted here is the angular distribution, and the multiplicity of charged particles from the collision increases in moving from the top to the bottom of the figure. The hydrodynamic flow angle is clearly evident, particularly in the heavier systems with high multiplicity.

Berekeley Laboratory has proposed a major upgrading of the Bevalac for use in the medium energy (i.e. less than or equal to 5 GeV per nucleon) heavy-ion energy regime; a competing but somewhat lower energy proposal has also been put forward by the Oak Ridge National Laboratory in the U.S.

THE NUCLEAR EQUATION OF STATE

Much of the interest in high-energy heavy ions can be associated with attempts to understand the equation of state for nuclear matter. Figure 34 is a somewhat reworked version of the much more familiar PV diagram familiar from classical thermodynamics. Here I plot temperature against the density, and the goal again is that of going from hadronic matter to quark-gluon plasma where the

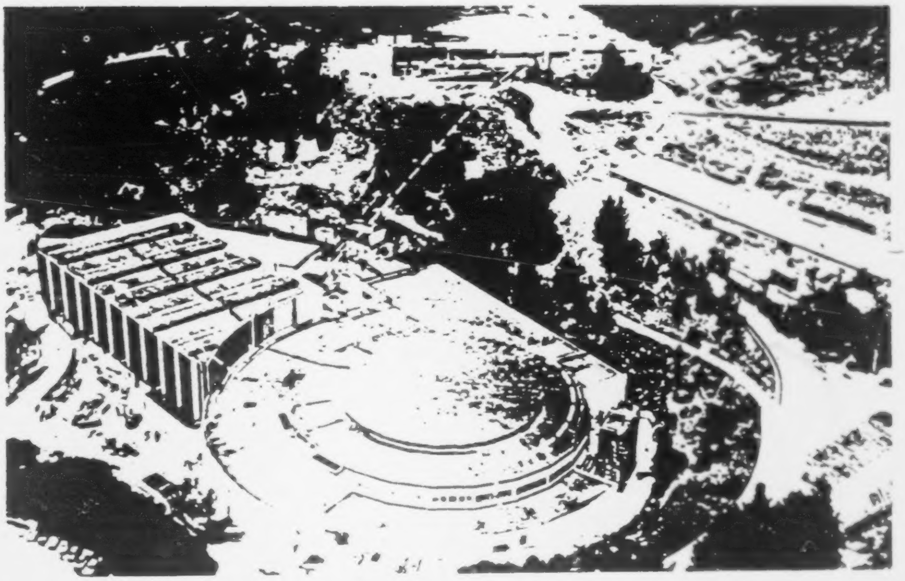


Figure 33: An aerial view of the Lawrence Berkeley site showing at the top the Superhilac injector. The arrow indicates the transfer line which passes across the Superhilac parking lot, then down a hillside to the old Bevatron building where the heavy-ion beam is injected into the synchrotron ring and accelerated to an energy in access of 2 GeV per nucleon before extraction into the large target hall on the left.

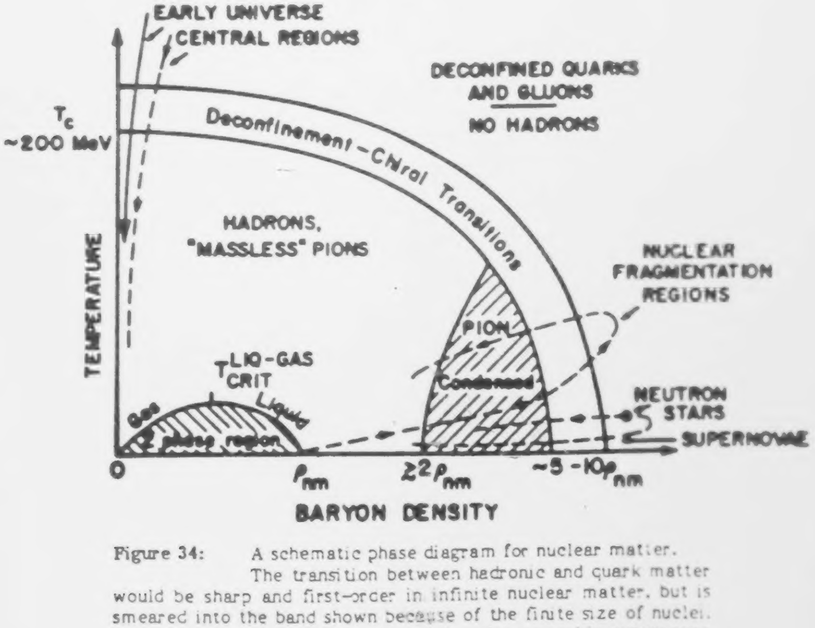
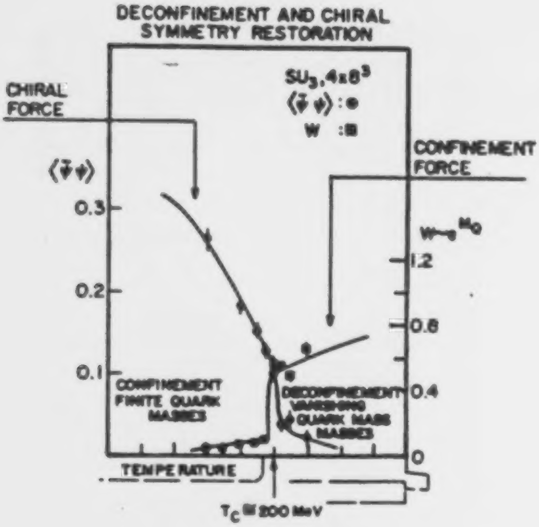

EARLY UNIVERSE
CENTRAL REGIONS
DECONFINED QUARKS AND GLUONS
NO HADRONS
T_c
~200 MeV
Deconfinement – Chiral Transitions
HADRONS, "MASSLESS" PIONS
NUCLEAR FRAGMENTATION REGIONS
TEMPERATURE
PION
Condensed
$T_{CRIT}^{LIQ-GAS}$
Gas
Liquid
2 phase region
NEUTRON STARS
SUPERNOVAE
0
ρ_{nm}
$\gtrsim 2\rho_{nm}$
$\sim 5-10\rho_{nm}$
BARYON DENSITY

Figure 34: A schematic phase diagram for nuclear matter. The transition between hadronic and quark matter would be sharp and first-order in infinite nuclear matter, but is smeared into the band shown because of the finite size of nuclei. The trajectories followed in the early universe and in supernovae creation of neutron stars are indicated as is the path anticipated in ultrarelativistic heavy-ion collisions leading to nuclear fragmentation. As indicated at density more than twice normal, it is anticipated that pion condensation should occur, whereas at densities less than normal liquid-gas phase transitions should be discernable.



COUPLED, FIRST-ORDER PHASE TRANSITIONS
(KOGUT et al., PRL 50, 393)

Figure 35: The results of coupled first-order phase transition calculations in lattice gauge theory. Shown here, as functions of temperature are the chiral and the confinement forces with an indicated critical temperature of 200 MeV.

quarks are entirely deconfined. If nuclei were of infinite extent, it would be assumed that the transition between hadronic and quark matter would be a first-order one at a precisely defined temperature for example; the fact that nuclei are of finite size, however, smears this transition region into the band shown.

There remains considerable ambiguity and uncertainty as to the actual parameters that should be applied to this diagram. The belief that the transition temperature should be something like 200 MeV comes from modern lattice gauge calculations with results such as those shown in Fig. 35. Plotted here as functions of temperature are the chiral force and the confinement force, the latter plotted as the Wilson parameter W. It appears clear from these calculations that at very low density, one would expect critical temprature of about 200 MeV. It is obvious from simple physical considerations that as the density increases, the critical temperature will decrease, as the bags containing the quarks in individual nucleons are pushed into closer and closer proximity. It is still, however, not clear at very low temperatures what density would be required to give deconfinement, although all calculations place this critical density somewhere between five and ten times normal nuclear matter density.

This figure shows a number of other interesting phenomena for which we can search. If indeed there is substantial compression in heavy-ion collisions—as the data of Fig. 32 suggest—then so also should there be rarefaction of the nuclear matter, and as shown in Fig. 34, a liquid-gas phase transition should occur. This should be observable in the characteristics of the fragments emitted from the collisions giving rise to the rarefactions. Considerable effort has already been devoted to searching for the pion condensation predicted in almost all models of heavy-ion collisions. The pion condensate, if it exists, would be an extremely interesting physical system in that a coherence phenomenon quite analogous to that of photons in a laser should be observable in the condensate. Unhappily, none of the measurements thus far have given any evidence suggesting its presence.

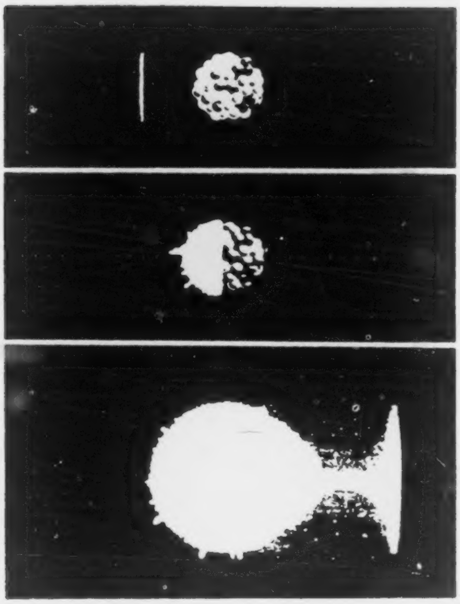


Figure 36: An artist's conception of the collision of a uranium projectile with a uranium target at ultrarelativistic energies. The upper panel shows the situation prior to the collision, the middle one during the collision and the bottom one immediately after the collision when both target and projectile have been raised to very high temperature and the so-called fire tube containing the quark gluon plasma has been formed between them.

As is clear from this figure, nature has already probed its behavior along both the temperature and density axes. During the expansion and cooling of the early universe, matter came down along the temperature axis, and in neutron stars and in supernovae, it is anticipated that densities in excess of the critical one are obtained. In accelerator induced collisions, the hoped-for phase path is indicated by the dashed line passing outward into the nuclear fragmentation region. Whether this is actually attainable or not remains to be determined experimentally.

Figure 36 is an artist's conception of the collision between an ultrarelativistic uranium projectile and a uranium target. David Shirley of LBL has commented that while this figure is long on relativity, it is very short on quantum mechanics; although this is unquestionably true, it is an instructive figure. The upper panel shows the incident uranium relativistically foreshortened into a disk just prior to its incidence on the target. As indicated earlier, at these energies, nuclei are essentially transparent to one another, so the projectile passes through the target but in doing so heats both the target and itself to extremely high temperatures. After passing through the target as shown in the lower panel, we have two regions, formerly the projectile and the target, now at very high temperature and still with high baryonic number, while in between is a region which we assume to have essentially zero baryon number but a high density of high temperature quarks and gluons—in other words, a quark-gluon plasma, a totally new state of matter. If we are to study this quark-gluon plasma, we obviously require

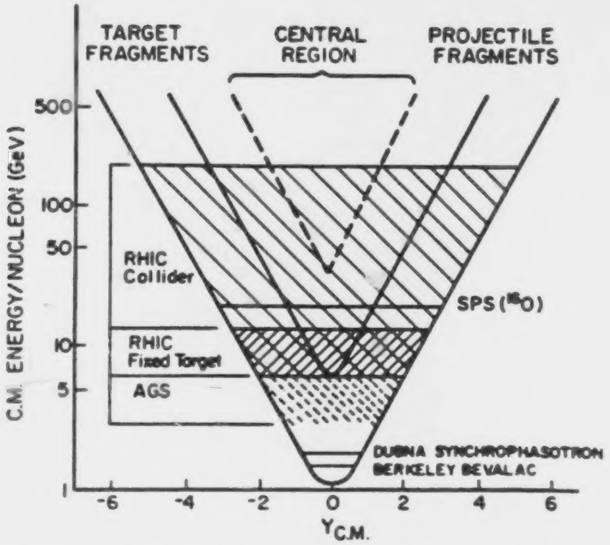


Figure 37: The kinematics of relativistic heavy-ion collisions plotted as a function of the center-of-mass energy per nucleon against the center-of-mass rapidity. The regions occupied by target and projectile fragments are shown, as is the central region where the quark gluon plasma—the fire tube—would be expected. Also shown on this diagram are the regions accessible to a variety of existing and proposed heavy-ion accelerators.

characteristic signatures for its presence. I shall return to this question below. We also however need to have the target and projectile-like regions sufficiently separated so that we can gain experimental access to the so-called fire tube containing the quark-gluon plasma. This raises the question of how high the projectile energies must be to achieve this separation.

This matter is addressed in Fig. 37 where I plot the center of mass energy per nucleon in GeV against the rapidity (effectively a measure of the momentum transfer). We are interested in the so-called central region well separated from the region containing either the target or the projectile fragments. I have shown on this figure the regions accessible to various present and proposed accelerators. Obviously, neither the Dubna Synchrophasotron nor the Berkeley Bevalac can give access to the fire tube, nor indeed can the AGS at Brookhaven when it becomes operational later this year. The SPS at CERN, which will accelerate ^{16}O beams later this year and ^{32}S beams next year, comes the closest of anything to be available in the near future. However, even it, as shown here, will be somewhat marginal in terms of giving adequate separation of the central region from the target and projectile regions with high baryon density. The only facility that truly makes available the central region is the Relativistic Heavy-Ion Collider (RHIC) now proposed by the Brookhaven National Laboratory and that operating in its collider rather than its fixed target mode. Figure 38 shows a schematic diagram of the proposed RHIC accelerator with the beam from the tandem Van de Graaff source being transferred to the alternating gradient synchrotron for acceleration up to 15.2 GeV per nucleon. This part of the facility will be functional in autumn of

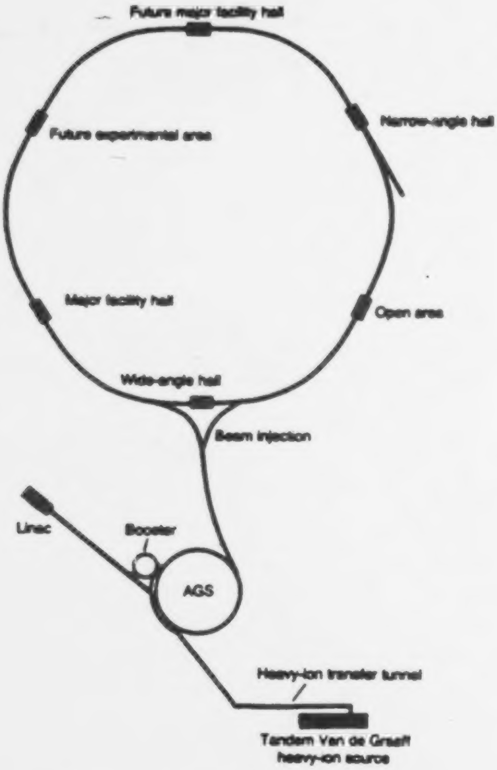

Future major facility hall
Narrow-angle hall
Future experimental area
Major facility hall
Open area
Wide-angle hall
Beam injection
Linac
Booster
AGS
Heavy-ion transfer tunnel
Tandem Van de Graaff
heavy-ion source

Figure 38: A schematic diagram of the proposed relativistic heavy-ion accelerator at the Brookhaven National Laboratory. The tandem Van de Graaff and the alternating gradient synchrotron with its linac injector are already in existence, as is the heavy-ion transfer tunnel. The booster synchrotron is approved for construction, and the tunnel and much of the associated hardware for the large ring are in existence following their construction as part of the ISABELLE high-energy physics project.

1986. Also approved for construction is the indicated booster which will increase the range of heavy ions from sulfur to gold and at the same time increase the proton beam intensity—and, therefore, the produced kaon flux—from the AGS by a factor of 4, making it into a mini-kaon factory.

The RHIC proposal will take the acclerated beam from the AGS, inject it into the existing tunnel constructed originally for the proposed high-energy physics ISABELLE accelerator and accelerate it further to 100 GeV per nucleon. With injection and acceleration in both directions in the main ring, it will then be possible to examine head-on collisions of these beams at the six indicated collision regions. Figure 39 is an aerial view of the Brookhaven site with the components of Fig. 38 shown in place. This proposal for RHIC has received the highest priority rating of the U.S. Nuclear Science Advisory Committee and approval in principle by the U.S. Department of Energy; now the question is one of phasing it into the national program in nuclear physics. The fact that the RHIC proposal uses essentially the entire prior investment in the ISABELLE accelerator makes it a remarkably cost-effective proposal and one that will give clear access to the

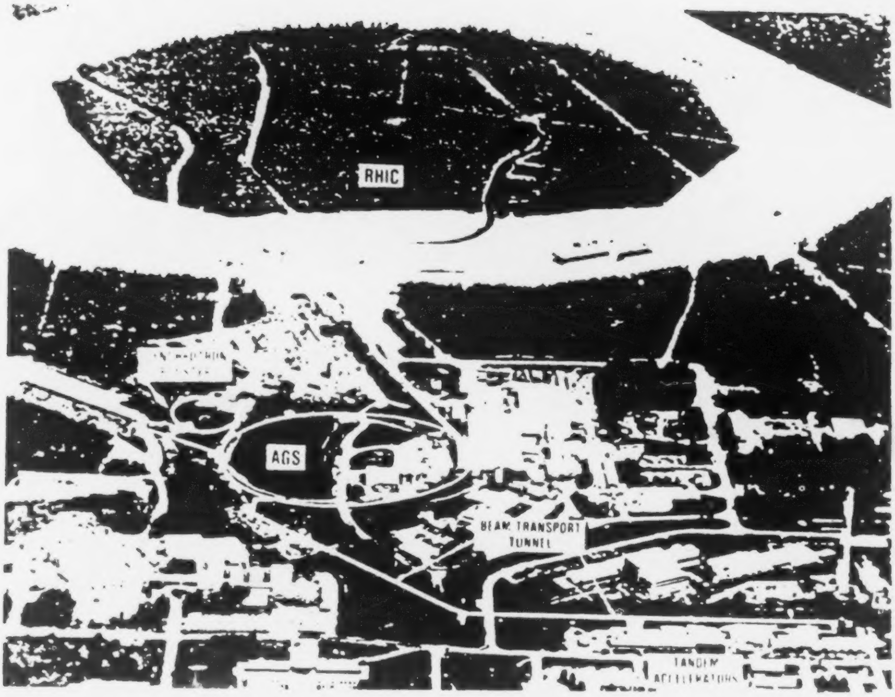


Figure 39: An aerial view of the Brookhaven National Laboratory's central site showing the various components of the proposed RHIC accelerator.

central rapidity region and, on the basis of current knowledge, to the quark-gluon plasma.

The proposal has received the highest priority rating from NSAC because it addresses some exceedingly fundamental problems in both nuclear and particle physics as well as in astrophysics. Among these are the deconfinement of quarks in nuclei, the creation of the quark-gluon plasma, the recreation of the early moments of creation, the physics of gravitational collapse of massive stars, the equation of state of nuclear matter, the possibility of entirely new kinds of matter, and the strong force including perturbative QCD. It bears emphasis that these studies are highly complementary to those now being carried out on the high-energy frontiers of particle physics. In particle physics, the emphasis is on delivering ever increasing energy to smaller and smaller volumes in the hope that this energy will be materialized into new particles; in nuclear physics the emphasis is on delivering ever increasing energy to volumes large enough to contain many nucleons (quarks) and thus large enough to permit the possibility of collective phenomena. The availability of a wide range of projectile and target species in these heavy-ion interactions also will be of great assistance in the isolation of specific interaction features and phenomena.

Figure 40 summarizes the status of heavy-ion accelerators in the U.S. and in Europe when RHIC is completed. The German project for an upgraded Bevalac (SIS) covers the same domain as indicated here for the Bevalac.

I have noted that signatures for the quark-gluon plasma are essential. Several have been suggested, including strange particle, antiparticles and lepton

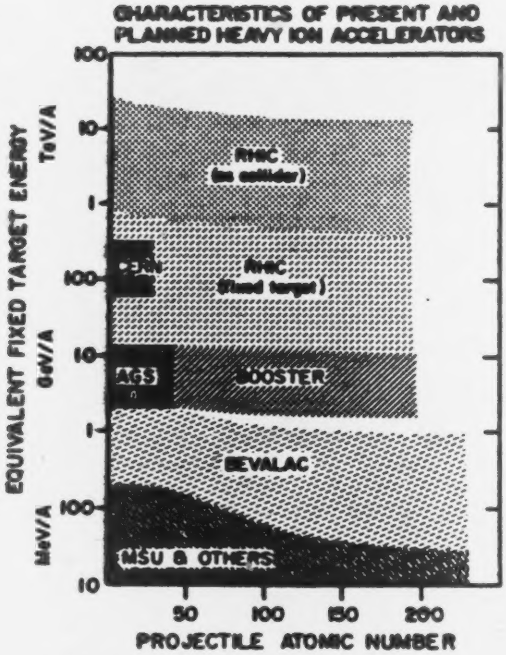


Figure 40: A Blann diagram showing the equivalent fixed target energy available from current and proposed U.S. and European heavy-ion accelerators as a function of projectile atomic number. The SIS accelerator under construction at GSI will have essentially the same profile as that shown here for the Bevalac.

pairs; but there is no clear concensus regarding the most sensitive or regarding the establishment of the natural background production rates of these signatures through a simple condensation of the plasma. Only experimental studies can shed light on these questions. And it is of particular importance that too much attention and expectation not be focused on the preliminary and limited studies that will become available later this year from Brookhaven and CERN. It may well be that these studies will indeed provide unambiguous evidence for the quark-gluon plasma--but if they do not, we must not lose heart and must remember that only very light projectiles will be involved, perhaps too light to generate an adquate fire tube.

THE IMPORTANCE OF HIGH-ENERGY PROTON MACHINES

Although not yet included in the national plan for U.S. nuclear physics, there is growing interest, worldwide, in the availability of more intense sources of kaons and higher mesons that will make possible the more commonplace introduction of strangeness into the nuclear domain. Substantial progress has already been made in this area using time on elementary particle physics machines at CERN, at Brookhaven and at Fermilab. Much of the emphasis thus far has been on the study of hypernuclei wherein reactions involving an incident kaon and outgoing pion convert one of the neutrons in the target nucleus into a lambda and thus create a hypernucleus. Povh and his collaborators at CERN as well as Barnes and others in the U.S. have already made substantial progress toward understanding the lambda-nucleon interaction, and as shown in Fig. 41, a substantial number of hypernuclei have already been studied.

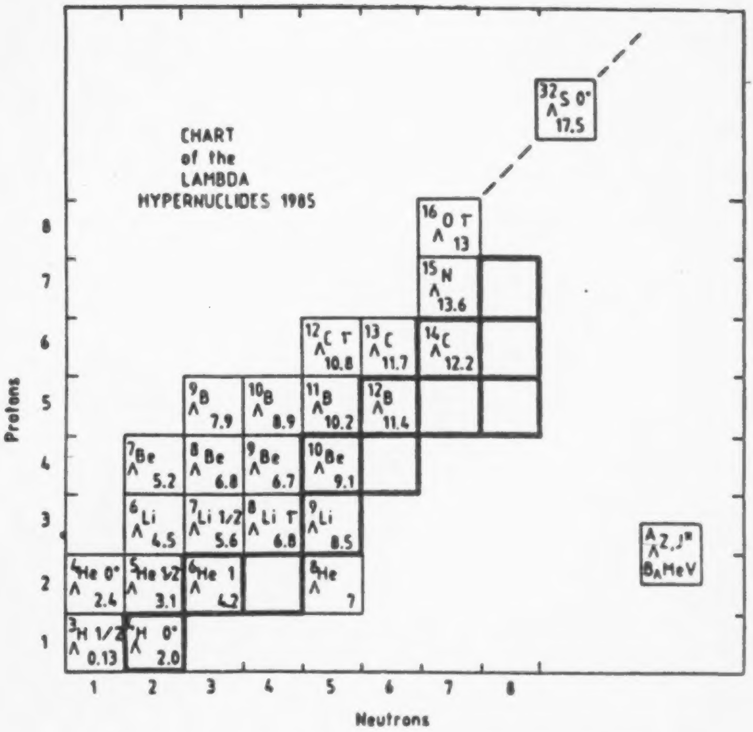


Figure 41: A Z vs. N plot of the lambda hypernuclei that have been identified and studied up to 1985.

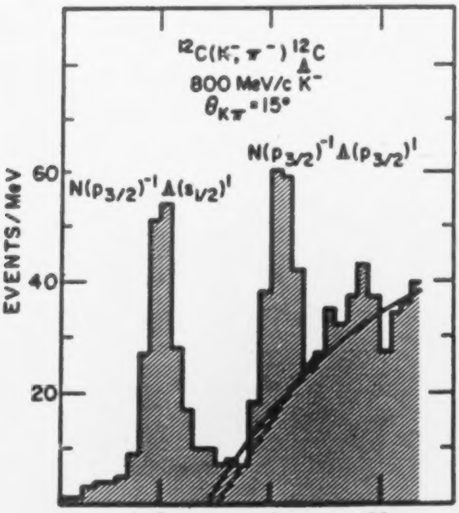
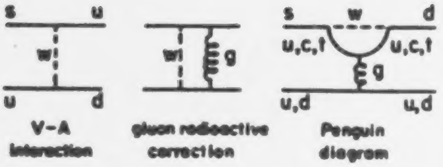


Figure 42: Typical spectra obtained in the (K^-, π^-) reaction on ^{12}C with 800 MeV/c kaons leading to the indicated lambda hypernuclear states.



$$H_{V-A} = \frac{G_F}{\sqrt{2}} \sin\theta_C \cos\theta_C \, O_{V-A} + \text{complex conjugate}$$

$$O_{V-A} = \bar{u}\gamma_\mu (1-\gamma_5) s \bar{d}\gamma^\mu (1-\gamma_5) u$$

G_F = Fermi coupling constant
$(1.4150 \pm 0.0011) \times 10^{-49}$ erg·cm^2

θ_C = Cabibbo angle = $0.269 \pm 0.001 = 15.4 \pm 0.06$ deg.

$\Delta I = 1/2$ and $3/2$ both allowed but $\Delta I = 1/2$ enhanced
by a factor $15 \leq F \leq 30$

$$-\frac{G_F}{\sqrt{2}} \sin\theta_1 \cdot \cos\theta_2 \cdot \cos\theta_3 \sum_j C_j O_j$$

Wilson coefficients: $C_1 = 1.51$, $C_2 = -0.87$; $C_3 < 10^{-2}$; $C_4 < 10^{-2}$

$$O_1 = O_{V-A} ; O_2 = \bar{d}\gamma_\mu (1-\gamma_5) s \bar{u}\gamma^\mu (1-\gamma_5) u$$

Figure 43: Feynman diagrams and the formalism for establishing strong interaction corrections to the vector axial-vector weak interaction decay occurring in lambda hypernuclei.

Figure 42 shows typical spectra obtained by Barnes and coworkers who have used their data on the decay of these hypernuclear states to investigate the inverse of the usual situation, in that they are looking for strong interaction corrections to the weak interaction. This is illustrated in Fig. 43 which shows these corrections to the normal vector-axial vector weak interaction mediated by the W boson. The pure weak interaction Hamiltonian is shown here as h_{V-A} while that in the presence of the strong interaction corrections is shown at the bottom of this figure. The first two Wilson coefficients—the large ones—correspond to the gluon radioactive correction whereas the latter two—the small ones—correspond to the so-called penguin diagram shown at the upper right of this figure.

Lambda hypernuclei are of course not the only ones available for study, and Fig. 44 shows a typical spectrum obtained for sigma hypernuclei produced in a reaction with incoming negative kaons and outgoing neutral pions. This entire field is in its infancy as yet and provides an entirely new way of probing not only the nuclear interior—because the Pauli principle permits the addition of strange hyperons into orbits that are already filled with nucleons—but also, as illustrated in Fig. 43, fundamental studies on the elementary interactions themselves.

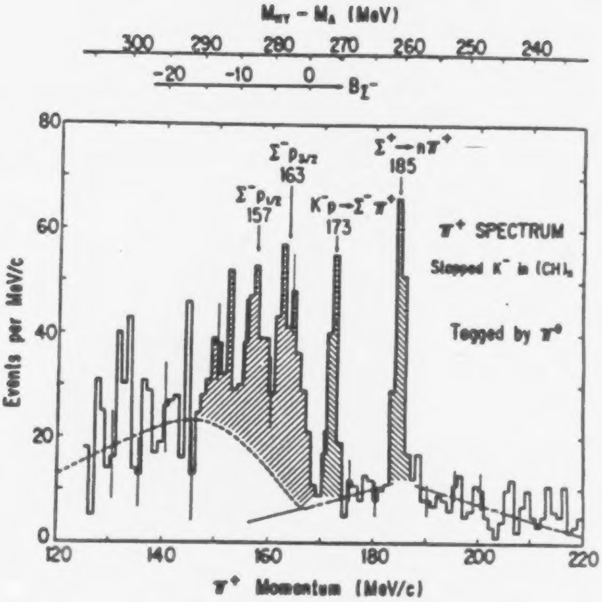


Figure 44: A typical positive pion spectrum from the bombardment of ^{12}C with negative kaons showing sigma hypernuclear states.

RARE KAON DECAYS

Since the discovery of the kaon, emphasis has been focused on the so-called rare decay modes because they provide stringent tests for the standard models. What is normally considered is the branching ratio defined as the ratio of the forbidden decay rate, as for example those shown at the top of the left panel of Fig. 45, to the allowed decay rate, that is, the decay of the kaon into a muon plus neutrino. The standard model suggests, for example, that the K^+ decay to $\pi^+ \nu \bar{\nu}$ should have a branching ratio of about 10^{-11}; but new interactions which have at least been proposed could raise this to between 10^{-9} and 10^{-10}, as shown here, while the presence of massive neutrinos could lower it to 10^{-12} as shown by the dashed line. Currently, the experimental limit is, as shown by the solid line, about 10^{-7}. This is shown in greater detail on the right of this figure where I show the branching ratio limits as a function of time, together with the number of positive kaons which were studied in the different experiments. It is clear that with the proposed kaon factories it would be possible to scan the regions of branching ratio predicted by the standard model, including variations with massive neutrinos and new interactions. Here, the relationship with elementary particle physics is a close one, of course, and this is a new area into which nuclear physicists are moving with enthusiasm.

Earlier I mentioned the EMC effect and the current uncertainty as to its explanation. In Fig. 46, I again show the experimental data and list four quite distinct and contradictory conclusions that have been published based on analyses of these results. As shown in the lower part of this figure, if we are to resolve this question and establish which of these four competing explanations is the valid one, it will be necessary to go beyond the deep inelastic scattering of electrons and muons. As shown here for electron and muon scattering, both quarks and antiquarks enter equally into the determination of the form factor, and the form factor is

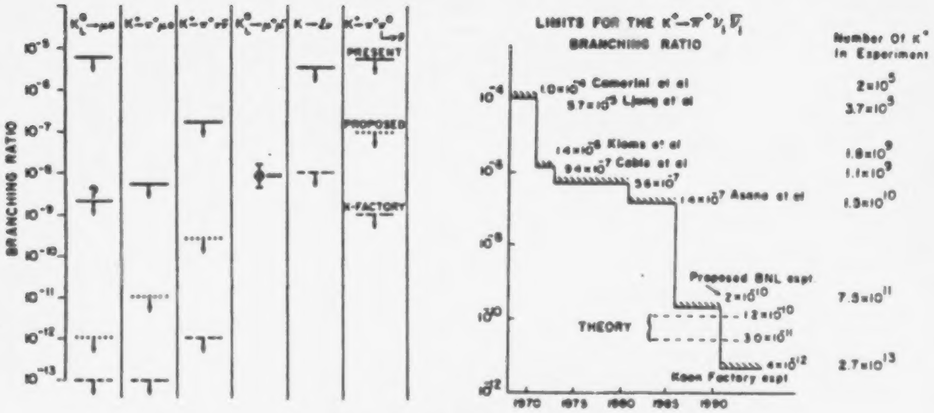


Figure 45: A schematic illustration of the present status concerning rare kaon decays. The figure on the left plots the branching ratio for a variety of rare decays. The solid line in each case marks the present limit, whereas the dotted and dashed lines span the range of uncertainty of current calculations of the predicted branching ratio. A more detailed presentation of the situation concerning the branching ratio for a specific rare decay is shown on the right, which includes also the number of positive kaons that have been studied in each of the indicated proposed experiments.

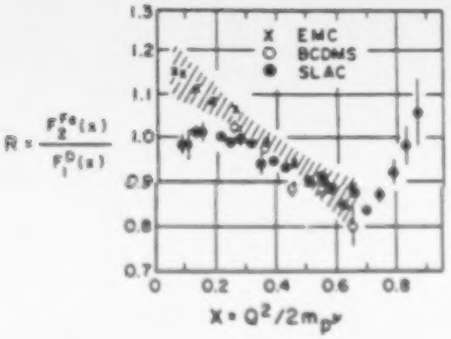
insensitive to flavor since it is summed over all three flavors. If instead one uses pions or kaons as the probe particles, one takes advantage of the Drell-Yan process which involves the production of virtual, very heavy photons. Now the ratio of form factors has two terms: pion scattering emphasizes the first term and therefore gives results that are similar to those obtained with electrons and muons; kaons, on the other hand, emphasize the second term and in consequence are sensitive to the presence of sea, as opposed to valence, quarks and are also sensitive to flavor. Thus, by comparing deep inelastic scattering of kaons with that of electrons, muons and pions, it should be possible to establish unambiguously which of the four alternative explanations listed in Fig. 46 is the physically valid one.

Kaon factories have been proposed in Canada, in Japan, in Switzerland and in the United States. In the U.S. case, the proposal is shown in outline in Fig. 47 and would make use of the Los Alamos 800 MeV proton linac as an injector first to a 6 GeV synchrotron ring and then to a 45 GeV ring. There is a wide range of fascinating physics that awaits the availability of facilities on this high-intensity frontier.

THE UNITY OF NUCLEAR PHYSICS

But let me emphasize that the physics does not separate neatly as a function of projectile energy. As I illustrate in Fig. 48, it is well recognized that the effect of the Z^0 boson is highly suppressed for in lepton-lepton and in lepton-hadron collisions. Where it would be expected to show up strongly is in the weak interaction between nucleons; but there, its detection becomes exceedingly difficult because of the presence of the strong interaction. In order to be able to detect the weak interaction effects at all, it is essential to have a signature which is unambiguously attributable to weak phenomena. Fortunately, this is available in parity nonconservation. What I plot in Fig. 48 is the asymmetry in the scattering of polarized protons from nucleons—in this case, from protons in hydrogen and water targets. The low-energy point was taken with the Los Alamos tandem accelerator, the next with the injector to the SIN cyclotron in Zurich, that at 800 MeV at the Los Alamos Meson Physics Facility and that at 6 GeV as the last experiment on the ZGS before its demise at the Argonne National Laboratory. What is important here

QUARKS IN NUCLEI



1. Valence quarks in nucleons deconfined but held in nuclear volume
2. Nucleon interactions produce multibaryon clusters
3. Nucleon size increases in the nuclear environment
4. Density effects on pion currents enhance quark sea

DEEP INELASTIC SCATTERING OF ELECTRONS AND MUONS

$$F_2(x) = x\sum_i e_i^2\left[q_i(x) + \bar{q}_i(x)\right]$$

Both quarks and antiquarks enter equally: insensitive to flavor

DRELL-YAN PROCESS

$$R_{DY}^{NA}(x_1,x_2) = \frac{\sum_f e_f^2\left[\bar{q}_f^{h}(x_1)q_f^{A}(x_2) + q_f^{h}(x_1)\bar{q}_f^{A}(x_2)\right]}{\sum_f e_f^2\left[\bar{q}_f^{h}(x_1)q_f^{N}(x_2) + q_f^{h}(x_1)\bar{q}_f^{N}(x_2)\right]}$$

Pion scattering emphasizes the first term – quarks

Koon scattering (or proton at large x_1) emphasizes

second term – sea quarks

Latter also sensitive to flavor

Figure 46: The upper panel shows the EMC data as a ratio of the iron to the deuterium form factors plotted as a function of the Bjorken scaling variable. Listed under the figure are the four quite distinct explanations that have been proposed in the literature for these data, and below that is the formalism for deep inelastic scattering of electrons and muons and of pions and kaons respectively, the latter invoking the Drell-Yan process and the creation of a virtual superheavy photon.

is to note first of all that the entire energy range from 10 MeV to 100 GeV is very important to understanding the phenomena involved. A precise series of measurements even at tandem accelerator energies could, for example, serve to distinguish between meson exchange and quark bag models, and a new series of high precision measurements under way at the TRIUMF facility in Canada will provide critical data between the second and third points on this figure. This provides an excellent illustration of the fact that the boundaries between nuclear and particle physics are completely artificial ones, and their crumbling in the past few years is a very healthy sign.

NONACCELERATOR NUCLEAR PHYSICS

After all this discussion focusing on accelerators, it is absolutely essential to emphasize that there is much exciting and challenging work to be done in nuclear

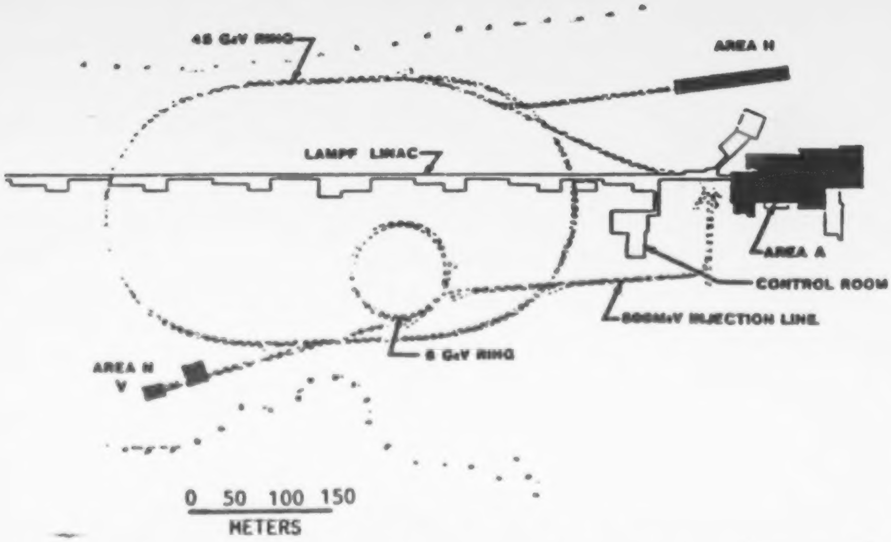

45 GeV RING
AREA H
LAMPF LINAC
AREA A
CONTROL ROOM
800MeV INJECTION LINE
6 GeV RING
AREA N
V
0 50 100 150
METERS

Figure 47: The proposed LAMPF II facility at Los Alamos. The existing 800 MeV proton linac will be used as an injector, first to a 6 GeV booster ring and then to a 45 GeV ring. The outline of the Los Alamos MESA is also sketched showing that the proposed facility occupies essentially all the available real estate at Los Alamos.

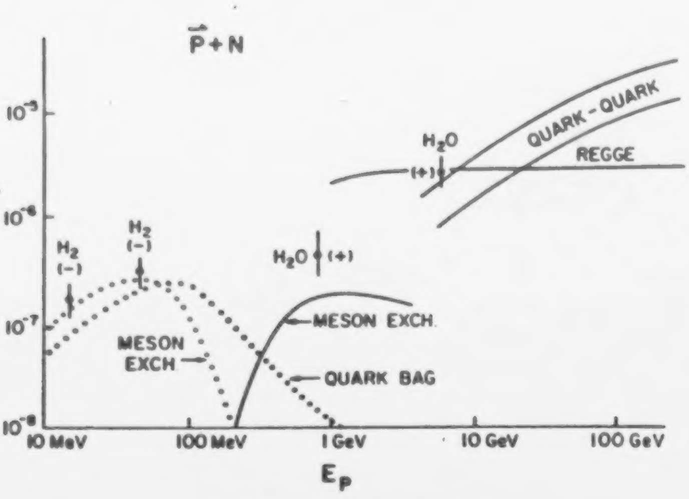


Figure 48: The asymmetry in the scattering of polarized protons from protons is here plotted against the energy of the incident polarized protons. The point at 15 MeV was obtained with the Los Alamos tandem accelerator that had 50 MeV, with the injector to the SIN cyclotron in Zurich, that at 800 MeV at Los Alamos and that at 6 GeV from the ZGS accelerator at the Argonne National Laboratory. Also shown here are the predictions of a variety of different models. It is clear that much more extensive and more precise data are required before any firm conclusions can be drawn.

SUPERALLOWED BETA DECAY STUDIES

Koslowsky *et al.* - Chalk River Nuclear Laboratories

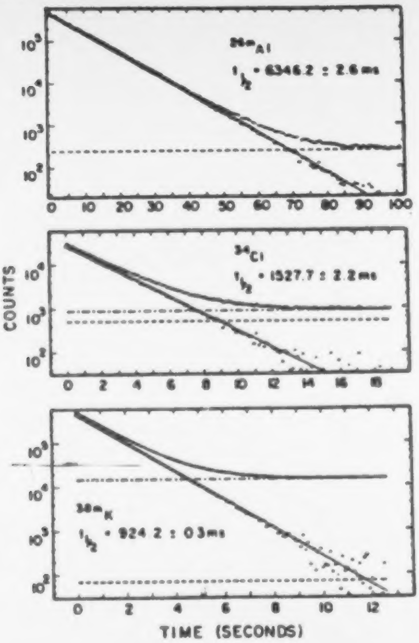


Figure 49: Typical decay curves in the study of superallowed beta decay at the Chalk River National Laboratories.

$$\underset{\text{weak eigenstates}}{\begin{bmatrix} d' \\ s' \\ b' \end{bmatrix}} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \underset{\text{mass eigenstates}}{\begin{bmatrix} d \\ s \\ b \end{bmatrix}}$$

By convention, the charge $^2/_3$e quarks are unmixed

Superallowed beta decays yield $|V_{ud}|$ = 0.9752 ± 0.0003

Hyperon and $K_{\ell 3}$ decays yield $|V_{us}|$ = 0.231 ± 0.003

Neutrino production of charm yields $|V_{cd}|$ = 0.24 ± 0.03

Assuming unitarity and only 3 generations yields the following values.

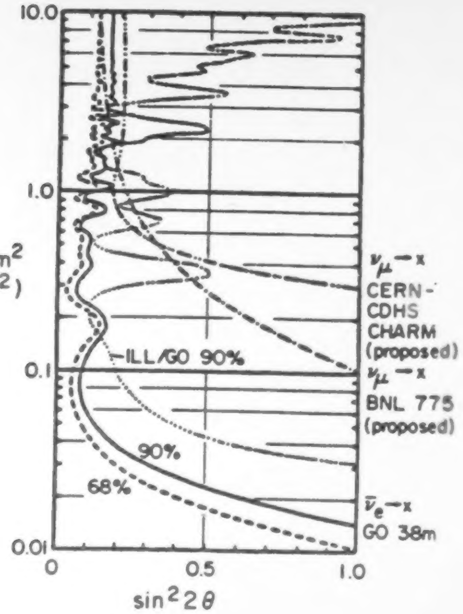
$|V_{ub}|$ = 0.007 ± 0.007 $|V_{td}|$ = 0.012 ± 0.012

$|V_{cs}|$ = 0.972 ± 0.001 $|V_{ts}|$ = 0.052 ± 0.017

$|V_{cb}|$ = 0.053 ± 0.017 $|V_{tb}|$ = 0.998 ± 0.001

Figure 50: The Kobayashi-Maskawa quark mixing matrix. As indicated, the superallowed beta decay data yields a determination of the appropriate matrix element with an order of magnitude greater accuracy than is obtained from the study of hyperon or kaon decays and two orders of magnitude greater than that obtained in the neutrino production of charm.

N.L. Vuilleumier *et al.* Phys. Lett. 114B 298 (1982)



$$P(\nu_{\ell 1} \to \nu_{\ell 2}) \sim \frac{\sin^2 2\theta}{2} \left[1-\cos(2.53\,\Delta m^2 (L/E_\nu))\right]$$

Figure 51: The current status of measurements setting limits on the mass of different neutrino flavors. The probability of oscillation between neutrino flavors is shown at the bottom of this figure and is a function both of the angle θ and of Δm^2, the square of the mass difference between the neutrino flavors. What is plotted here is Δm^2 vs. the $\sin^2(2\theta)$, and the region to the right of each of the curves has been excluded by that experiment. As is obvious the only nonexcluded regions now correspond to very small values of θ or to very small values of Δm^2.

physics that requires no accelerator at all. Beta decay studies since the earliest days of our field have continued to provide vital new information. In Fig. 49, for example, I show measurements on superallowed beta decay from the Chalk River Laboratories and, in Fig. 50, how the results of these superallowed decays provide by far the most precise input we have to establishing the matrix elements in the Kobayashi-Maskawa quark mixing matrix. Figure 51 illustrates yet another very topical area where beta decay and neutron oscillation searches are of critical importance in attempting to establish limits on the mass of different neutrino flavors. Additional studies on double beta decay, for example, continue to provide critical information on lepton number conservation and other important questions in nuclear and particle physics. The list is a long one and one that shows no sign of dwindling.

THE FRONTIERS OF MODERN NUCLEAR PHYSICS

Together, all of these areas make up the frontier of nuclear physics, as I illustrate in very highly schematic fashion in Fig. 52. Nuclear physics is by its very

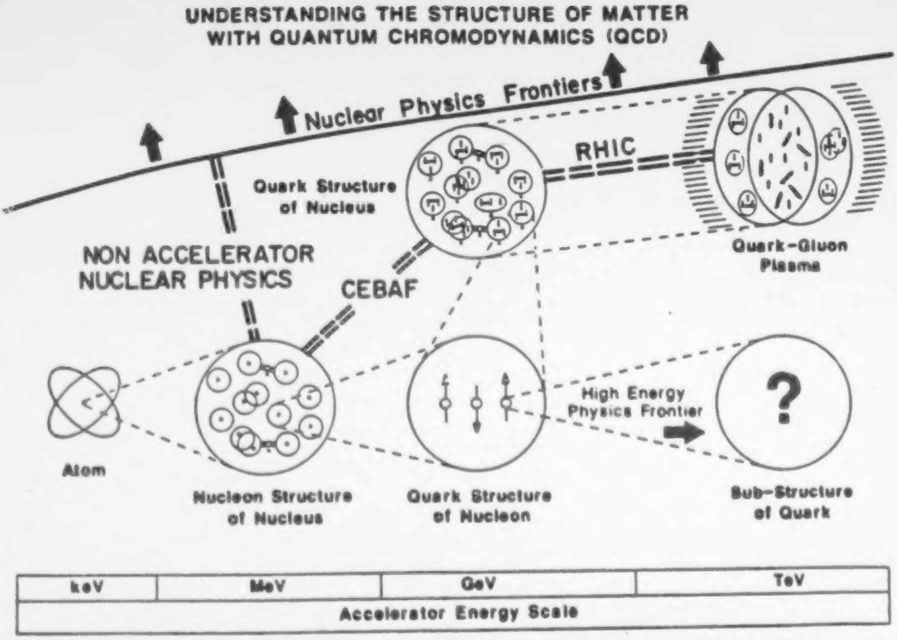

UNDERSTANDING THE STRUCTURE OF MATTER
WITH QUANTUM CHROMODYNAMICS (QCD)
Nuclear Physics Frontiers
RHIC
Quark Structure of Nucleus
Quark-Gluon Plasma
NON ACCELERATOR NUCLEAR PHYSICS
CEBAF
High Energy Physics Frontier
?
Atom
Nucleon Structure of Nucleus
Quark Structure of Nucleon
Sub-Structure of Quark
keV
MeV
GeV
TeV
Accelerator Energy Scale

Figure 52: A very schematic illustration of the frontiers of modern particle physics and of modern nuclear physics. Shown here is the full range of activities beginning with the atom with its characteristic keV energies moving to the nucleus considered as a complex of nucleons with its characteristic MeV energy range and on to higher energies. At the GeV level, the quark structure of the nucleon and, therefore, of the nucleus becomes apparent while it moving to TeV energies in the nuclear physics domain, the emphasis is on the quark-gluon plasma and on collective phenomena that might be involved in this new state of matter. In particle physics, in the TeV domain, the emphasis is on the possible substructure of the quark itself and the testing of the predictions of the now standard model and variants of it. In particle physics, the frontier is toward ever higher energies, whereas in nuclear physics the frontier is a broader one ranging all the way from nonaccelerator nuclear physics to that in the TeV range on the quark-gluon plasma. The role of CEBAF in moving from hadronic to quark structure of the nucleus is indicated here, as is that of RHIC in moving from quark structure of the nucleus to the anticipated quark-gluon plasma.

nature a very broad ranging science, and information from beta decay can be of critical importance in the understanding of phenomena measured at the highest energies available from our largest accelerators. It is essential that we keep this fabric intact and that we recognize the interdependence of the different areas represented within our field and on its boundaries with other sciences.

Although this is not the place to develop it, it bears emphasis too that in a major way the future of nuclear physics is strongly coupled to its many applications in other sciences, in technology and throughout society. Nuclear physics in many ways is unique in its scope, both intrinsic and extrinsic, in the range of phenomena it covers within science and in the range of problems to which it can make a contribution in contemporary society.

It also bears mentioning that those trained in modern nuclear physics have, not through any intrinsic merit of the field but rather through a rather happy coincidence, had to develop a systems approach to their work in order to make progress. Students in our field must learn to mobilize the resources and talents of a wide range of technologies and support personnel if they are to make progress; they develop confidence in attacking what at the beginning frequently appear to be broad, unstructured problems; they develop personal expertise in a wide ranging variety of specialties and techniques; and, perhaps most important, they develop personal confidence in their ability to tackle problems that are completely new to them. For these reasons, they have tended to be successful in a very broad spectrum of activities outside of nuclear physics and have been recognized as welcome partners in the search for solutions to broad societal problems.

I believe that we are currently entering one of the most challenging and exciting times in the history of nuclear physics and that nuclear physics has important contributions to make in its concepts, its instrumentation, its techniques and, most of all, its people to science, to technology and to society at large. I am happy to see the beginning of the disappearance of artificial boundaries which have tended to separate us from our colleagues working in other parts of physics. We have much to contribute and much to learn from them.

I should like to conclude by thanking Walter Greiner for his invitation to prepare this review and to thank all those, too numerous to mention, with whom over the years I have had the opportunity to discuss aspects of the material presented herein. Most particularly, I would thank my students and faculty colleagues in the Wright Laboratory at Yale with whom I have interacted over the past 20 years. It has been a great pleasure working with them, and they have taught me a great deal. I would also particularly thank Ms. Annalee Jacunski for the preparation of camera-ready copy for this publication.

YALE 3074-943

THE NUCLEUS-
ITS IMPACT ON SCIENCE AND SOCIETY

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Yale University

Prepared for presentation at a luncheon sponsored by
THE DIVISION OF NUCLEAR PHYSICS-AMERICAN PHYSICAL SOCIETY

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INTRODUCTION

I particularly welcome the opportunity to speak to this audience about nuclear physics, a science that still remains at the frontiers of human knowledge and at the same time continues to have important and direct societal applications. Over 98% of our known universe is nuclear and a great many of the laws that govern its birth, growth and death—as well as much of our role in it—are nuclear laws. In the time at our disposal this afternoon, as I show in **Slide 1**, I would propose to touch, very briefly, on four topics: first of all the science itself, then its facilities, then its applications, and finally, a few comments about its people.

Turning to the science itself, as I show in **Slide 2**, there have been several rather striking trends in this science in recent years. First of all, with new facilities, new detection equipment, and new information handling equipment, the quality of our experimental data has increased dramatically. Secondly, we have begun to appreciate that there are new symmetries, new simplicities, that determine what happens in the nuclear manybody system; this has made it possible for us to unify and extend much of the theoretical understanding that we have had previously and it has enabled us to ask entirely new questions that are important not only in nuclear physics but throughout physics as a whole.

Going beyond that, the horizons of our science have expanded and the boundaries with many of our sister sciences such as particle physics, material science, astrophysics, and chemistry have blurred. Frequently we find our ideas, our concepts, and our equipment moving across these boundaries; I think that this is a remarkably healthy situation. Beyond that, these transfers are moving into the much broader areas of technology and to attacks on some of the major societal problems that we face today.

THE SCIENCE

a) Nuclear Structure

Let me begin by illustrating the renaissance that is taking place in our attempts to understand the structure of the nuclear quantum system. Slide 3 illustrates this for the case of a particular nucleus, ^{168}Er, where I show the first 127 quantum states in this nucleus. We have established the quantum numbers and all the major characteristics of these states and, as you can see, have been able to classify them into 36 distinct families. Each of these families is characterized by a particular symmetry behavior. All of these states, however, are close to the nuclear ground state; they are characteristic of cold nuclei and it is important to recognize that, in the past 75 years since Rutherford discovered the nucleus, our studies of it have been limited to such cold systems. Moreover, they have been limited to the characteristics of the nuclear surface, to the behavior of neutrons and protons in that surface, and to relatively slowly spinning nuclei.

One of the most dramatic developments during the past year took place at the Daresbury Laboratory in England; as shown in Slide 4, whereas previously it had always been considered an experimental triumph to obtain information on quantum states having up to about 30 units of angular momentum, Daresbury experiments—at one pass—doubled the range of accessible spins and have opened up, for the first time, to precision study the very interesting regions where the nuclear system becomes unstable against centrifugal disintegration and where we become particularly sensitive to the details of the nuclear forces holding the system together against this disintegration.

b) Hot Nuclei

With the ability to move up in spin and in energy to hotter nuclei, we are just beginning to address the fascinating question of how the nucleus behaves at higher temperature; Slide 5 shows some preliminary results in this area. The limited measurements that have been made thus far suggest that, if a nucleus starts out cold with a spherical shape, as it is heated and as it spins more rapidly it first becomes oblate (doorknob shaped) then develops a triaxial or ellipsoidal shape and finally becomes prolate (football shaped) and as it spins ever faster it stretches more and more (superdeformed) until it eventually tears itself apart. By applying the techniques of quantum statistics—so-called Landau Theory—to such a hot nuclear system, as shown in this Slide, it has become possible to predict that there should be phase transitions—more familiar to most people as the freezing and boiling of water, for example—but phase transitions within the nucleus as it moves from one of these characteristic shapes to the other. But can we detect these phase transitions as the nucleus is heated? Present calculations suggest that if we look at the so-called giant resonance wherein all the neutrons and all the protons oscillate together against one another and in the process emit gamma radiation, the shapes of the experimental observed giant resonances—the number of these gamma rays as a function of energy—provide unique signatures for the shapes involved. Both the energy width and the shape of the predicted peak are expected, over small energy intervals, to change at the predicted phase transition. Only very preliminary data are available as yet, from the University of Washington, but the first of these phase transitions has apparently already been seen and the others remain open for exploration.

The symmetry concepts underlying the new nuclear structure studies have given us framework within which it is possible for us to understand, and, for the first time, make unifying calculations on **all** nuclei in nature rather than just those in isolated regions to which certain special models, shell models, liquid drop models, and other similar models had been found to apply.

c) Nuclear Dynamics

There are early indications that a similar unification may be possible in the case of nuclear dynamics. Although, as yet, we are only at a very preliminary stage, we already have promise that a symmetry approach may allow us to unify our understanding of the way in which nuclei interact with one another. In the past, we have used different models, different pictures, to understand elastic and inelastic scattering, transfer reactions, deep inelastic scattering, and so on. As I show in **Slide 6**, where I have plotted data for four different interactions between ^{16}O and ^{24}Mg nuclei as measured at the Argonne National Laboratory together with the results of the symmetry based calculations it appears possible to reproduce the experimental results in rather dramatic fashion and on a completely unified basis. Our goal in the next few years is to obtain adequately precise data sets to allow us to establish whether this unification of our understanding of nuclear dynamics is, in fact, generally valid.

d) Positron - Electron Pairs from Heavy Nuclear Collisions

As a last example of the kind of work that is now being done with so-called low energy facilities—tandem Van de Graaffs, cyclotrons, and linear accelerators—based both in the universities and in the national laboratories—in **Slide 7** I show what are still very puzzling results obtained by a US-German collaboration at the UNILAC facility in Germany in the study of collisions of very heavy nuclei—in this case uranium and curium. Focusing on the left-most column in the Slide one sees the spectrum of positrons associated with these collisions and the totally surprising result, obtained a few years ago, the sharp peak superimposed on the continuous and reasonably well understood positron spectrum. This sharp peak implied that the positrons were coming from some long-lived state or entity associated with the collisions. More recently, as shown in the second column, in the course of much more difficult experiments—since the electron background is a factor of 10 million greater—again a sharp line of the same energy appears in the spectrum of electrons associated with the collisions. If now the positron and electron spectra are studied in time coincidence, in the third column one sees that the summed electron-positron peak is even narrower than either of the positron or electron peaks themselves. This implies that the correlated electrons and positrons are being emitted together from a slowly moving source and the possibility arises that they are being emitted in the decay of some entirely new entity with a mass somewhere between 1 and 2 MeV/c^2. It is fair to say, at this time, that we have no good idea what this entity might be, but the experimental measurements have triggered an enormous amount of interest in theoretical circles in particle nuclear, and atomic physics. Whatever the final explanation may be it is already clear that it will involve entirely new physics.

e) The Nuclear Interior

I mentioned earlier that essentially all of our work over the past 75 years has been confined to the nuclear surface. One of the open questions has always been whether neutrons and protons deep in the interior of a heavy nucleus retain the same characteristics as when they are on its surface or when they are free. **Slide 8** shows recent results obtained by Bernard Frois and his colleagues at Saclay, from studies on the inelastic scattering of electrons on ^{206}Pb and ^{205}Tl nuclei differing by only in the presence of a 3s proton. Because the electron interacts via the long-range electromagnetic interaction and not, as do nucleons through the short-range strong nucleon interactions, it illuminates the entire nuclear volume; the French group then argued that by subtracting their data they could effectively determine what is shown here as the square of the wave function for this single s-wave proton deep in the nuclear interior. What they found was an absolutely classic 3s wave function, suggesting that indeed nucleons—neutrons and protons—do behave the same deep in the nucleus as they do its the surface.

f) The Transition from Hadronic to Quark Matter

Such electron beams, in moving to higher energy, provide a convenient way of tracking the behavior of these nucleons, as they are heated beyond the low temperatures to which I have already referred. **Slide 9** shows this rather dramatically. In the interaction of electrons with protons—here plotted both as a function of energy loss and momentum transfer—the small peaks on the left correspond to the scattering of electrons from the familiar proton, while the next peak, labeled Δ , corresponds to the situation where the proton itself soaks up energy and becomes excited to its first quantum state. As more energy is added, the protons (and of course neutrons as well) become more excited and we see the nucleon isobars, the N^* excitations and, as we go to even higher temperatures, we find that the nucleons, each of which consists of three quarks and the gluons that bind them together, begin to melt. This is very much reminiscent of the melting of glass, in that it is a slow, gradual transition—a transition from hadronic matter, matter that is governed by the behavior of neutrons and protons, into quark matter, that governed by quarks and gluons, and an entirely new fifth state of matter. This is an extremely complex transition but because of that complexity it can tell us an enormous deal about both of these kinds of matter and about their relationship as well as about how the quarks are confined in the nucleons. It is clear also from this Slide that if one really wishes to examine this transition region one needs electron energies somewhere in the range between 4 and 6 GeV.

g) Relativistic Heavy Ion Collisions

There are other ways of heating nuclei and indeed producing temperatures in the laboratory, if only for very brief periods, that previously existed only in the instants after the Big Bang of creation. **Slide 10** is an artist's conception of a collision between two uranium nuclei, that on the left moving at an ultra-relativistic velocity—close to that of light. Because it is ultra-relativistic, its linear dimensions, of course, have shrunk in the direction of travel so that we see it as a disk edge on approaching a spherical nucleus at rest. As the nuclei move through one another, an enormous amount of energy is transferred to both as the kinetic energy of motion is dissipated; extremely high temperatures result. As shown in the lower panel, at these energies nuclei are essentially transparent to one another—apart from this heating effect—and so after the collision we are left with a region dominated by target fragments and one dominated by projectile fragments. What lies between, however, is the so-called fire-tube, and it is in this region that we might hope that we will be able to see a pure quark-gluon plasma for the first time.

It is important to emphasize here the difference between the goals in nuclear physics and in particle physics in moving to ever higher energies; this I show in the next Slide, **Slide 11.** In particle physics the attempt is to deliver evermore energy to ever smaller volumes in the hope that some at least of it will materialize into new and previously unknown particles. In nuclear physics, on the other hand, the attempt is to deliver evermore energy to relatively large volumes so that we can hope to see not only new collective phenomena but also the development of this new quark form of matter.

h) The Equation of State of Nuclear Matter

All of this is pertinent to one of the major questions facing nuclear physics today, a question of tremendous importance in cosmology and in astrophysics as well. This is the equation of state of nuclear matter—how does it behave under varying density and temperature. This I show on **Slide 12** as a plot of temperature against density, a phase diagram for nuclear matter. If we heat the nucleus sufficiently, we believe to about 200 MeV, or if we increase the density sufficiently, we think to somewhere between 5 and 10 times its normal value, then we push the nucleons together so tightly that again they melt and their constituent quarks become deconfined. This would be a sharp transition if the nucleus was of infinite size, but because the nucleus is finite, the transition is smeared into the band shown on this slide. This particular phase diagram has, of course, been probed before. In the moments after the Big Bang, as the universe cooled, we passed down through the transition region as shown. In supernovae, and in gravitational collapse, we pass along the density axis as shown and, again, presumably pass through the transition. What we would like to be able to do, is to pass through this transition region—into the region of quark matter—in a controlled fashion using accelerated beams and this is the motivation for the present thrust both here and abroad, toward the study of relativistic heavy ions.

i) Collisions at 200 GeV per Nucleon

Both at Brookhaven and at CERN, we have, in these past few months, seen the results of actual experiments carried out at 15 and at 200 GeV per nucleon, respectively. On **Slide 13**, I show some very preliminary results of two experiments carried out at CERN by very large collaborating groups involving both European and American investigators. In the top panel I show a streamer chamber photograph of what happens when a 200 GeV per nucleon oxygen beam strikes a lead target and my purpose in showing this is simply to indicate how enormously complicated these interactions are and, therefore, what sophisticated instrumentation is required to make sense out of these collisions. In the bottom panel data I show from another experiment, this time with 200 GeV per nucleon oxygen on uranium; clear evidence emerges for formation of the now familiar J/ Ψ particle, originally found at Brookhaven and Stanford in high energy proton and electron induced experiments. This is a clear signature that in these ultra-relativistic heavy ion collisions we are also producing charmed quarks and makes it clear that as these heavy ion studies move forward the boundaries between nuclear and particle physics will dissolve—as they should.

j) The High Intensity Frontier

The above are examples of what we expect on the high-energy frontier. There is, however, yet another frontier, that of high intensity—a frontier where one focuses on very rare events, which are very difficult to see, very difficult to measure, but which can be extremely important in our understanding of nature. **Slide 14** is an illustration of such a measurement carried out recently at the Los Alamos National Laboratory on the scattering of neutrinos by electrons. When one realizes that a 1 MeV neutrino can pass entirely through the earth with very high probability, one recognizes the difficulty inherent in making such measurements. The only reason they are possible is because of the extraordinarily high beam intensity obtainable at the Los Alamos Meson Physics Facility and, therefore, the great number of neutrinos available. What is found here is a very sharp peak, about 0°, resulting from the scattering of neutrinos from electrons. The important thing is that, since both the electron and the neutrino are leptons interacting via the electroweak interaction, it is possible to calculate what this scattering should be in terms of the interference between effects carried by the Z^0 and the $W^\pm$ vector bosons recently discovered at CERN. In such calculations a predicted cross section is found—as shown in this Slide—that is in remarkably good agreement with the experimental measurements. This adds very considerable support to what is now known as the Standard Model for fundamental interactions on which these calculations are based.

k) Non Accelerator Nuclear Physics

In the time available, I have, of course, mentioned only a very few representative studies from the low energy, electron, heavy ion, and high intensity frontiers, respectively. All are complementary in that results from one frontier illuminate and makes understandable those from others; all are important.

I would be remiss, however, were I not also to emphasize that in addition to these frontiers, all of which are related to use of accelerators, there remains an extremely important area of nuclear physics requiring no accelerators whatever. As our knowledge of the nucleus becomes more detailed and more precise it becomes possible to use the nucleus as a microscopic laboratory in which the most fundamental interactions in nature can be tested and studied. Current studies on double beta decay, for example, test the fundamental assumption of lepton conservation—an observed law of nature for which we have no fundamental understanding—and promise to provide evermore stringent limits on the possible rest mass of the neutrino. This is a matter of enormous importance not only in physics but also in astrophysics and cosmology where massive neutrinos could provide the missing mass needed to bring the expansion of our universe to an end.

The search for proton decay also remains fundamental to our understanding of the Standard Model as does that of the rare decays of the kaon.

New non-accelerator measurements are now being planned in nuclear physics that will greatly extend our understanding of parity conservation in nuclei and of time reversal noninvariance.

FACILITIES

a) The NSAC Long-Range Plan for US Nuclear Physics Facilities

I have thus far given only a totally fragmented view of some of the frontiers in nuclear physics at the present time—high temperature, high spin, high density, high energy, and high intensity. Obviously, to reach these frontiers requires very special facilities. This is a matter that has been under consideration by the Nuclear Science Advisory Committee (NSAC) reporting both to the Department of Energy and to the National Science Foundation for the past many years. Responding to requests from these agencies, the NSAC first in 1979 developed a systematic long-range plan for the development and construction of facilities that would keep US nuclear physics at its frontiers and competitive with world activity in the years ahead. This long-range plan was revisited in the summer of 1983 and, sometime in the near future, will require a further revisiting. There have been several components to this plan. First of all, it has been recognized that in moving to new and more demanding frontiers with higher associated costs, it will be necessary to phase-out some of the older and less productive facilities. It has also been recognized that it is critically important to maintain a balanced program—balanced in the sense that we try to maintain activity on all the major frontiers of our science and that we maintain a very active component of the science in a number of the nation's universities where the next generation of students in our field receive their training as well as at the major national facilities which, of course, are also used extensively by university based groups.

My next few Slides illustrate some of our major facilities. **Slide 15** is a somewhat artistic overview of the ATLAS facility at the Argonne National Laboratory. This consists of a superconducting linac post-accelerator injected by a medium-sized tandem accelerator. It is characteristic, if you will, of a whole class of so-called low energy accelerators based at national laboratories and universities, accelerating a wide range of projectiles from protons to uranium and addressing the first class of problems that I mentioned earlier. As recommended in the long-range plan, a number of these facilities have recently been upgraded and made much more powerful both at national laboratories and universities. US facilities in this class are competitive with those elsewhere in the world.

Slide 16 shows the schematic structure of the continous electron beam accelerator facility (CEBAF) now under construction at Newport News, Virginia. It consists of two superconducting linacs, each rated at 0.5 GeV with magnetic recirculator arcs such that the electron beam can be passed through the linacs repeatedly to achieve energies certainly up to 4 GeV and probably up to 6 GeV when this facility is completed in the early 1990's. The upper panel is simply an artist's conception of what the completed facility will look like; the three circular areas in the foreground are the heavily shielded target areas. With its 100% duty cycle and its energy range the CEBAF facility will be unique and unmatched elsewhere in the world.

I noted earlier that relativistic heavy ion beams are just becoming available both at Brookhaven and at CERN. **Slide 17** is an aerial view of the Brookhaven site with a superimposed layout of both the present and proposed facilities. Heavy ion beams are produced in the tandem accelerators at the lower right, transferred to the, by now rather ancient, alternating gradient sychrotron (AGS) for acceleration up to 15 GeV per nucleon. These beams are already in existence—at least up to ^{32}S. Under constrution is a new booster, which will not only increase the proton beam of the AGS by a factor of 4--and therefore the secondary kaon beam—but also will make it possible to increase the range of accelerated heavy ions from ^{32}S to ^{198}Au. After acceleration in the AGS, if the construction of the proposed relativistic heavy ion collider (RHIC) moves forward, the beams of the AGS will be transported into two magnetic rings in the tunnel at the top of the slide that was originally constructed as part of the Isabelle particle physics project and will then collide at up to six locations around this ring. Because something like $250 million had already been invested in facilities for the Isabelle project which are directly pertinent to the heavy ion one, the RHIC proposal can be a very cost effective one and would result in 200 GeV per nucleon collisions. This is a factor of 10 more center of mass energy than can be obtained at CERN under any current scenario and makes RHIC a truly unique proposal. Now that the CEBAF construction is underway, RHIC is the item of highest priority in the Nuclear Science Advisory Committee's long-range plan.

Slide 18 is a schematic illustration of the proposed advanced hadron facilities at Los Alamos showing the 1.2 GeV high intensity proton linac, together with a 2 GeV compressor ring, a 15 GeV booster and the 60 GeV main ring as well as several of the proposed target areas. This proposed arrangement—commonly referred to as a kaon factory because of the enormous flux of strange kaons that could be produced in it—would also be a unique facility worldwide, but it has not yet been included in the NSAC long-range plan.

Slide 19 is a somewhat crude attempt to show where all these facilities fit together in our attempt to understand the structure of matter.

In **Slide 20**, I summarize the present status with respect to nuclear physics facilities in this country. It is important to notice that in 1969 there were 90 university-based, accelerator-based programs supported by the NSF and by the then AEC, whereas today, only 5 remain supported by DOE and 11 by NSF. The roster of existing and proposed facilities is as shown. It is important to emphasize, on the basis of these data, that the nuclear physics community has **already** closed down a large number of facilities in moving toward larger and more modern ones. If we are to maintain the desired balanced program, and, if we are to continue to educate an adequate number of young nuclear physicists, we face the difficult problem of maintaining a sufficient number of our existing smaller but still very productive facilities in a state of robust health while we move forward to the new frontiers. Already some of our existing high-quality facilities are being significantly under-utilized and promising graduate students are being turned away from nuclear physics programs for lack of available support. I return, however, to these questions below.

APPLICATIONS

Slide 21 is a brief summary of some of the areas wherein nuclear physics has already had substantial impact on our society. We have, for example, a long history of development of new techniques and I list a number of them here.

Nuclear energy needs no emphasis at this time in either its civilian or military incarnations other than to note that we have been much less successful than other countries in taking advantage of the nuclear energy option. It is my own feeling, unfortunately, that until we are either forced by environmental effects, such as acid rain or the CO_2 greenhouse affect, to limit our fossil fuel consumption, or until we develop entirely new modular, standardized reactor designs, which are more acceptable to our public, we can expect no substantial change in this situation.

Nuclear medicine remains one of the faster growing specialties in biomedicine, both diagnostic and clinical, and it is worth remembering a quotation from Phil Handler, the former President of the National Academy of Sciences and himself a distinguished biochemist who said,

> Biological sciences have been moved forward 50 years in the past 5 through adoption of many of the techniques of nuclear physics.

And finally, as the nation becomes more aware of the environmental problems that we face more and more frequently it turns to nuclear physicists for the technology that can measure environmental contaminants at concentrations that are still sufficiently low to allow time for corrective action.

Let me then illustrate only a few random examples of recent applications of nuclear physics in a wide variety of sister sciences and technologies.

a) Ion Implantation and Use of Ion Beams

As we move to evermore closely packed integrated electronics, the traditional techniques of construction will no longer suffice. We are just now reaching the stage (0.2 micron circuit element dimensions) where we must make the transition from chemical etching to ion beam induced sputtering for the removal of material in integrated circuit construction. Using ion implantation techniques, we can also move away from the two-dimensional architecture that has characterized essentially all of our integrated circuits to date and begin to construct three-dimensional architectures, within the silicon or gallium arsenide crystal substrate, by implanting the desired dopant atoms directly as accelerated beams. One of the serious problems with large scale integrated circuits, which superficially may seem rather trivial, is that of the contacts through which the outer world communicates with the intricate internal structure. These contacts have an unhappy tendecy to fail mechanically and to become non-ohmic, or rectifying, so that the functioning of the circuit is destroyed. **Slide 22** illustrates some success that we have had in a joint program involving Caltech and Yale in attempting to understand this general question of adhesion. What is shown is a gold film sputtered onto a teflon substrate. The horizontal ladder rungs are regions where heavy ions have been bombarded through the gold film into the teflon before a standard Scotch tape test was applied to the film. As is obvious where there was no bombardment there was no adhesion but at an optimum ion beam dosage, which differs depending upon whether the substrate is an insulator, as here, or a semiconductor, or a metal the adhesion is complete and, in fact, the film can only be removed with a razor blade. Beyond that, on semiconductors and on metals these films make pure ohmic contacts and remain that way for at least the periods of years that we have measured thus far. Ion beams are clearly one of the important tools of the future in the entire electronics industry and there are a great many examples of their use that I could have selected.

•

b) Ultra-Sensitive Mass Spectrometry

The nucleus also provides a clock, which, if you will, was set ticking when the solar system was formed and which has never been reset. Most of you are very familiar with the use of ^{14}C as a dating technique, where one determined the amount of ^{14}C present by detecting its decay. It was recognized sometime ago, initially by Mueller at Berkeley and by groups at Rochester and McMaster Universities that, if instead of waiting for the decay, one measured directly the number of ^{14}C atoms present, one could greatly increase the sensitivity—by factors of a million and more. This technique has been extended to many other radioactive nuclear clocks and on **Slide 23** I show you a result obtained in our own Laboratory at Yale measuring the age of a manganese nodule from the floor of the Pacific by measuring the amount of ^{10}Be in each of its growth rings. As shown, initially this particular nodule grew at the rate of 5.5 mm per million years, then the abundance of minerals in the Pacific ocean water in its vicinity decreased and, in more recent years, it has grown at something like 2.3 mm per million years. This is a whole new technology and worldwide a number of laboratories are now being set up with the sole purpose of using many different nuclear clocks with tandem accelerators devoted to these programs to measure the ages of samples of geological, archaelogical, and anthropological interests.

Perhaps the greatest immediate interest in this field, centers on a worldwide project, just now underway, to once and for all determine the age of perhaps the most famous relic in Christendom, the Shroud of Turin. A small section of the Shroud is shown in a positive print in **Slide 24**. Within the next year, seven laboratories around the world, under the aegis of the Papal Academy, will measure the age of samples taken from the Shroud at the same time and under the same conditions as a variety of control samples, prepared at the British Museum from fabrics of known age.

c) Nuclear Medicine

Slide 25 illustrates two quite different aspects of nuclear medicine. What I show here are brain scans, using positron-emission-tomography (PET) of a 21 year old male ski instructor who had developed a gliobeastoma in his brain. These scans were obtained, in May 1985, using ^{11}C labeled glucose. Using this technology it is possible to actually measure the functioning, the activity of the brain, as well as its structure and it is clear on the upper left that in the region of the tumor there is no activity at all and greatly reduced activity in a penumbra surrounding the tumor. The tumor was then treated by pion bombardment using the TRIUMF facility in Vancouver. Pions were arranged to deliver their kinetic and disintegration energy into the heart of the tumor and this particular scan simply shows radioactive debris remaining in the patient's brain after the therapy. In September 1985, a new PET scan shows very definite shrinking of the tumor and in April 1986 not only has the tumor disappeared but also much—and more important—apparently normal functioning has returned to almost the entire area that had previously been blacked out. From a clinical point of view, this young man, who would unquestionably have been dead had it not been for this treatment, is functioning in perfectly normal fashion.

It is estimated that something over 10 million Americans receive nuclear medical treatments each year at the present time and the number will unquestionably grow.

d) Muon Catalyzed Fusion

Turning back for a moment to the energy field, many of you will remember that in the mid-1950's there was a brief period of excitement when Alvarez and his collaborators, at Berkeley, reported the first observatons of muon catalyzed fusion, a phenomenon suggested as possible by Sakharov in the 1940's. This phenomenon follows from the fact that the muon is about 207 times heavier than the electron and the atom or molecule that contains a muon is correspondingly some 207 times smaller than those containing an electron. What Sakharov and Alvarez pointed out was that in this much more compact hydrogenic molecule it might be possible to bring the nuclei close enough together to have them undergo nuclear fusion. Unfortunately, the early measurements on HD molecules did not live up to the original promise because too many of the muons were lost, did not form molecules, and therefore did not lead to fusion. What changed this picture dramatically was the recognition by the Russian author Vesman that, in fact, in the case of DD and DT molecules, resonant formation was possible. This has been followed up by Jones and his collaborators from Brigham Young University and Los Alamos and the present state of the art as shown in Slide 26 is that a single muon catalyzes 150 fusions before it is lost or decays. The best calculations to date suggest that somewhere between 100 and 300 fusions per muon is the break-even point where it becomes possible to design a net energy producing system. This is a very exciting new development. It can have very important consequences in terms of the future of fusion energy and is being pushed enthusiastically at Los Alamos at the present time.

d) Environmental Studies

This muon work uses one of the nation's most modern and powerful facilities, the Los Alamos Meson Physics facility. My next Slide, Slide 27, shows work done at one of the most ancient and honorable of American nuclear facilities, the Crocker Cyclotron at the University of California, Davis. At the present time, fully 40% of the operating cost of this facility is born by outside contractors interested in environmental matters. Typical of this work, are the results shown in this slide on the concentration of fine sulfur, in other words, a precursor of acid rain, across the United States measured on a seasonal basis from sampling systems set up systematically in the national parks. Sampling the air over a period of several weeks, these samples are collected, returned to Davis, and in something less than 100 seconds are analyzed for quantitative concentration of all the contaminants of interest using proton induced x-ray emission (PIXIE) techniques. These are by far the highest quality data available on the spatial and temporal variation of the acid rain precursors. One of the surprising consequences of these studies was that the smog (or fog, as you prefer) in the Great Smokey Mountains, in summer, is 85 ± 5% manmade; beyond that, by looking at the signature of trace elements in the smog it can be unambiguously identified as having originated in the coal burning power plants of the Tennessee Valley Authority!

All of my applications thus far are fundamentally dependent on the availability of accelerators. In no one of these cases would the investigator, if presented with the problem, have ever thought of going out to construct an accelerator. What is required is that nuclear scientists and students—while working in nuclear physics—be sensitized to the possible applications of their techniques and equipment in a much broader spectrum of activity.

e) Nuclear Techniques in Art History

My last application, shown in **Slide 28** is an illustration of the use of a reactor in art history. The panel at the upper left is a painting of Van Dyke entitled, **St. Rosalie Interceding for the Plague Stricken of Palermo,** and is in the collection of the Metropolitan Museum of Art. The panel on the upper right is an X-radiograph of this same painting showing the construction of the canvas and its support and also the presence of a hidden under-painting which includes what appears to be the face of a man upside down at the bottom of the picture. None of the details, however, can be made out in the X-radiograph. The painting was exposed to a neutron flux from the Brookhaven reactor and, immediately after this neutron activation, was placed in contact with a large photographic plate. The result obtained in this first early autoradiograph is shown at the lower left and in particular shows the manganese which was present in the umber pigment used by Van Dyke in his preliminary sketching. The location of some modern repairs are also immediately obvious by the fact that umber was not used, hence, the white areas in the autoradiograph. It is also interesting to note that the angel above and behind St. Rosalie's head in the final painting does not appear in the original umber under-drawing but was apparently added later for improved balance. The panel at the lower right shows a second autoradiograph that was begun four days after the neutron activation, in this case emphasizing the phosphorus present in the bone black used by Van Dyke in his original under-drawing. The man's head is clearly delineated and a comparison of this autoradiograph with a self-portrait of Van Dyke—also in the Metropolitan Museum—shows beyond question that the under-painting was another self-portrait of Van Dyke.

Obviously this ability to unravel a painting gives the art historians an entirely new dimension to their craft. They can, in effect, watch over the shoulder of the old master as the painting comes together element-by-element.

Here again I have only been able to give a faint flavor of the great many modern applications of nuclear techniques and technologies to problems of broader societal importance. It also bears emphasis that although some of these applications were recognized very early in the history of the science and have thus been with us for decades, entirely new applications are turning up and at an accelerating rate.

PEOPLE OF NUCLEAR PHYSICS

It is becoming increasingly recognized that training in nuclear physics fits our students for a rather broad range of career opportunities. In our own case at Yale, for example, over the last many years, we have found that our nuclear physics Ph.D's follow a rather constant career distribution, with 40% in industry, 40% in academic positions, and 20% in government and other activities spread over a very wide range. I would feel that we had failed in our responsibility as educators if some such distribution were not the case and if all of our nuclear physicists wished to remain in our own field.

The success of nuclear physics as a training field is, in some sense, accidental. It reflects the fact that problems that are still on our intellectual frontiers remain within the grasp of a single graduate student so that that student can be completely responsible for the planning and execution of the research problem. At the same time, however, if the student is to be successful it requires that he or she be able to take a systems approach. Progress comes only from the cooperative effort of engineers, technicians, other student colleagues, faculty members, and the like. At the same time, a modern nuclear physics experiment requires experience in a broad range of techniques many of which are listed on **Slide 29** and this combination of a systems approach and broad experience in many technologies, I believe, leads to an unusual degree of self-confidence that makes it possible for these students to tackle the kind of broad, unstructured problems, which tend to be those of greatest societal importance with unusual enthusiasm and effectiveness. It makes them attractive partners in the search for solutions to major societal and industrial problems.

That this is so is emphasized by the fact that many of the leading developed countries, including those I have listed on this slide, have tended to focus their physics research activities into nuclear physics to a much greater extent than we have and are quite open in discussing the fact that they do so because they believe this to be an effective way to develop and maintain their national technology bases.

CONCLUSIONS

You will have formed the impression by now that I am enthusiastic about nuclear physics and about its future. Nuclear physics is an integral part of the overall fabric of physics and the connections between the different subfields of physics and, indeed, the unity both of physics and of all science is becoming more and more obvious. I believe that this is one of the most exciting times in the history of our entire field and that the next decade will witness both great progress and many surprises.

We are fortunate in this country in having one of the strongest nuclear physics enterprises in the world. This strength is the consequence of enlightened support over the years by the Congress and by the American taxpayer. Even under our present conditions of fiscal stringency, and in the face of a mounting deficit those responsible for the planning of federal support of science and technology in this country have seen fit to make continuing impressive investments.

Although there is frequently and understandably a tendency for those of us in the nuclear physics community to be concerned about underutilization of some of our facilities and about the fact that we cannot take on as many bright young people as would wish to join us, at the same time, I think that we must be realistic about the competition for federal support and recognize that we have been, and are being, well treated.

All too frequently we have not been as appreciative as we should have been of the stalwart efforts on our behalf made by Senators and Congressmen and their staff officers, nor have we provided them with the help and support that would have made their tasks easier. On behalf of all of us, I would like to take this opportunity to express that appreciation—as well as the hope that in future our responses to your requests for information and assistance will be faster and more effective.

Unfortunately, too, because we have devoted too little effort to telling the public, as well as our more immediate friends, what we are doing, what the importance of what we are doing might be, what the applications of our science are, and how broadly spread these applications are, there has been, in some circles, a feeling that nuclear physics may have passed through a golden age in the 1950's and that the excitement then present in nuclear physics has now passed to other sciences. In my opinion, nothing could be more wrong.

In closing the 1960 International Nuclear Physics Conference in Kingston, Canada, Viki Weisskopf summed up the situation then as follows:

> Physics inquires into the nature of things. The nucleus, our nucleus, is an essential part of nature; it is the center of the atom. It is not just a little phenomenon, it is the most prominent constituent of matter. The understanding of the phenomena occurring in this nucleus is, therefore, of paramount importance——don't let yourself be talked into believing that the nucleus is not interesting. It is so small and has so few parts and still it shows a tremendous variety of phenomena. Its investigation requires the whole arsenal of presently available experimental techniques, and its

> **understanding makes use of almost all branches of theoretical physics. What a marvelous invention! It is worth devoting a lifetime to it.**

What Weisskopf said in 1960 is certainly true in 1987. Having devoted a large part of my career to nuclear physics I can only say that it has been great good fun. I believe too that it has been useful and I envy my students who are entering the field at one of the most exciting times in its history. I have every confidence that they will continue to justify, in the most effective fashion, the investment that the nation makes in the support of our science.

NUCLEAR PHYSICS

SCIENTIFIC AND SOCIETAL IMPACT

A. THE SCIENCE

B. ITS FACILITIES

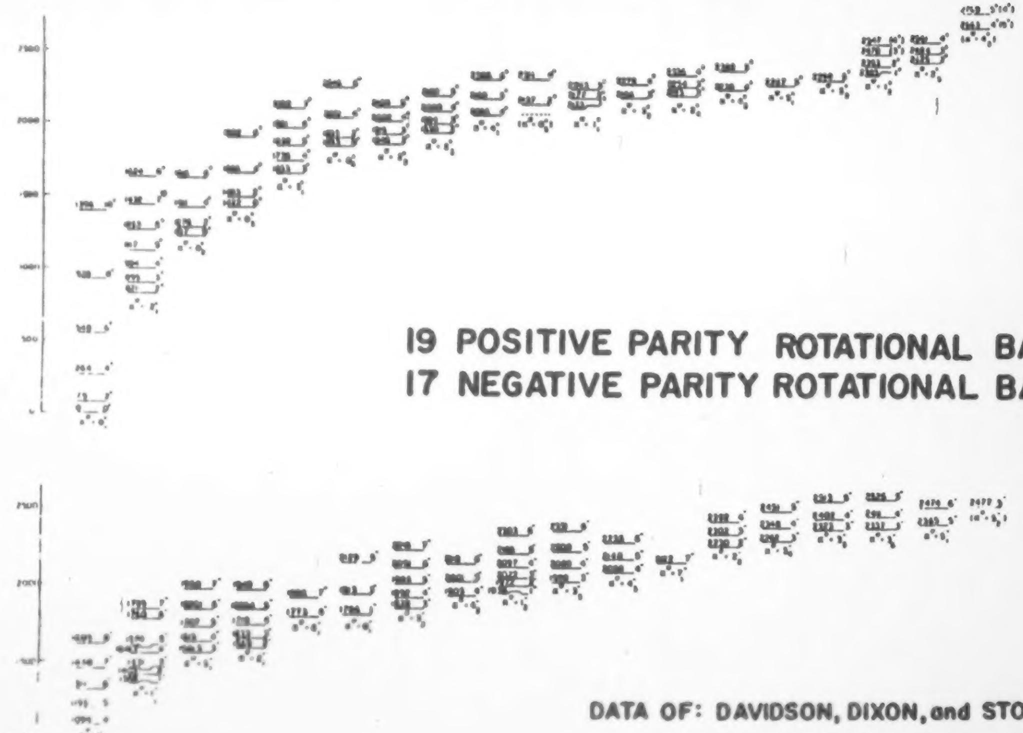
C. ITS APPLICATIONS

D. ITS PEOPLE

TRENDS IN NUCLEAR PHYSICS

- QUALITY OF EXPERIMENTAL DATA HAS INCREASED DRAMATICALLY WITH NEW ACCELERATORS AND INSTRUMENTATION
- NEW FOCUS ON UNDERLYING DYNAMIC SIMPLICITIES AND SYMMETRIES IN BOTH NUCLEAR STRUCTURE AND DYNAMICS
- EXPANSION OF HORIZONS AND BLURRING OF BOUNDARIES WITH SISTER SCIENCES BOTH IN, AND OUTSIDE OF, PHYSICS
- WIDESPREAD APPLICATION OF TOOLS, TECHNIQUES, CONCEPTS AND PEOPLE OF NUCLEAR SCIENCE TO TECHNOLOGY AND TO ATTACKS ON MAJOR SOCIETAL PROBLEMS

THE LOWEST 127 QUANTUM STATES OF ^{168}Er



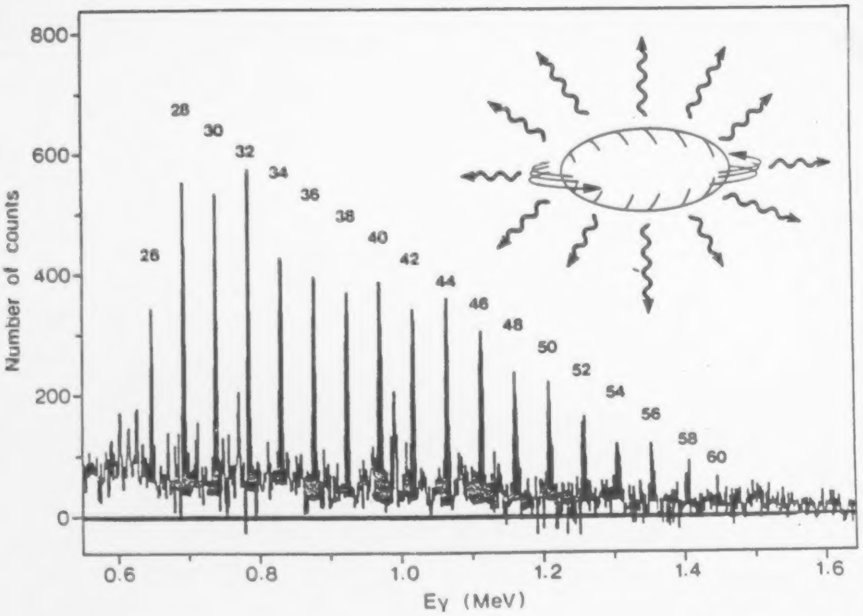
19 POSITIVE PARITY ROTATIONAL BANDS
17 NEGATIVE PARITY ROTATIONAL BANDS

DATA OF: DAVIDSON, DIXON, and STOREY
CAN. J. PHYS. 62 1538, 1984

Slide 3

GAMMA RADIATION FROM SUPER DEFORMED DYSPROSIUM NUCLEI

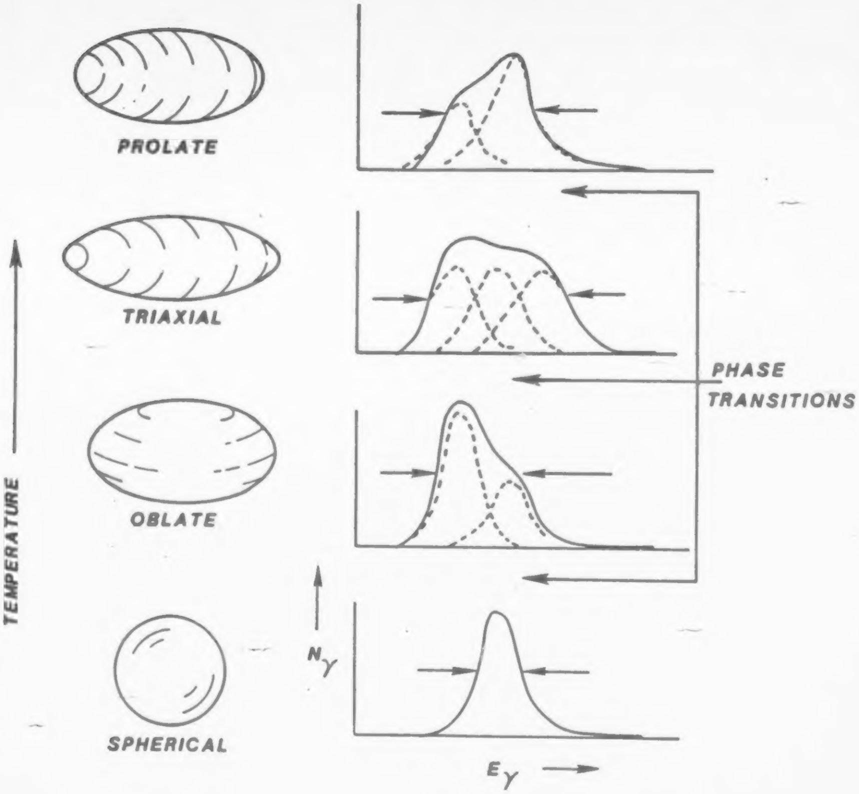
Peter Twin et al. Daresbury Laboratory



Slide 4

GIANT DIPOLE RESONANCES IN HOT NUCLEI

Theory: *Y. Alhassid et al. Yale University*
Experiment: *K. Snover et al. University of Washington*

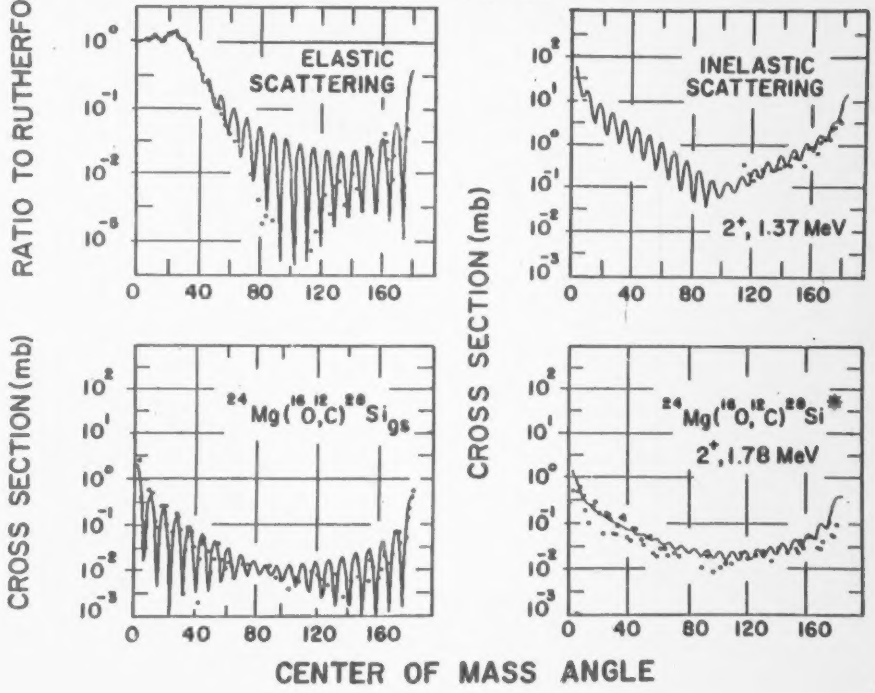

PROLATE
TRIAXIAL
OBLATE
SPHERICAL
TEMPERATURE
PHASE TRANSITIONS
N_γ
E_γ

Slide 5

$^{16}O + ^{24}Mg$ INTERACTIONS

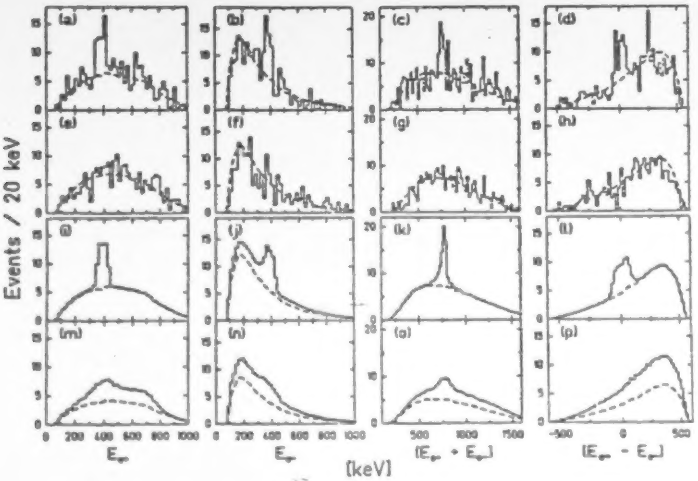
EXPERIMENTAL DATA: PAUL et al., Argonne

CALCULATIONS: Alhassid, Iachello and Shao, Yale.



Slide 6

ELECTRON - POSITRON COINCIDENCE EVENTS
URANIUM PLUS CURIUM



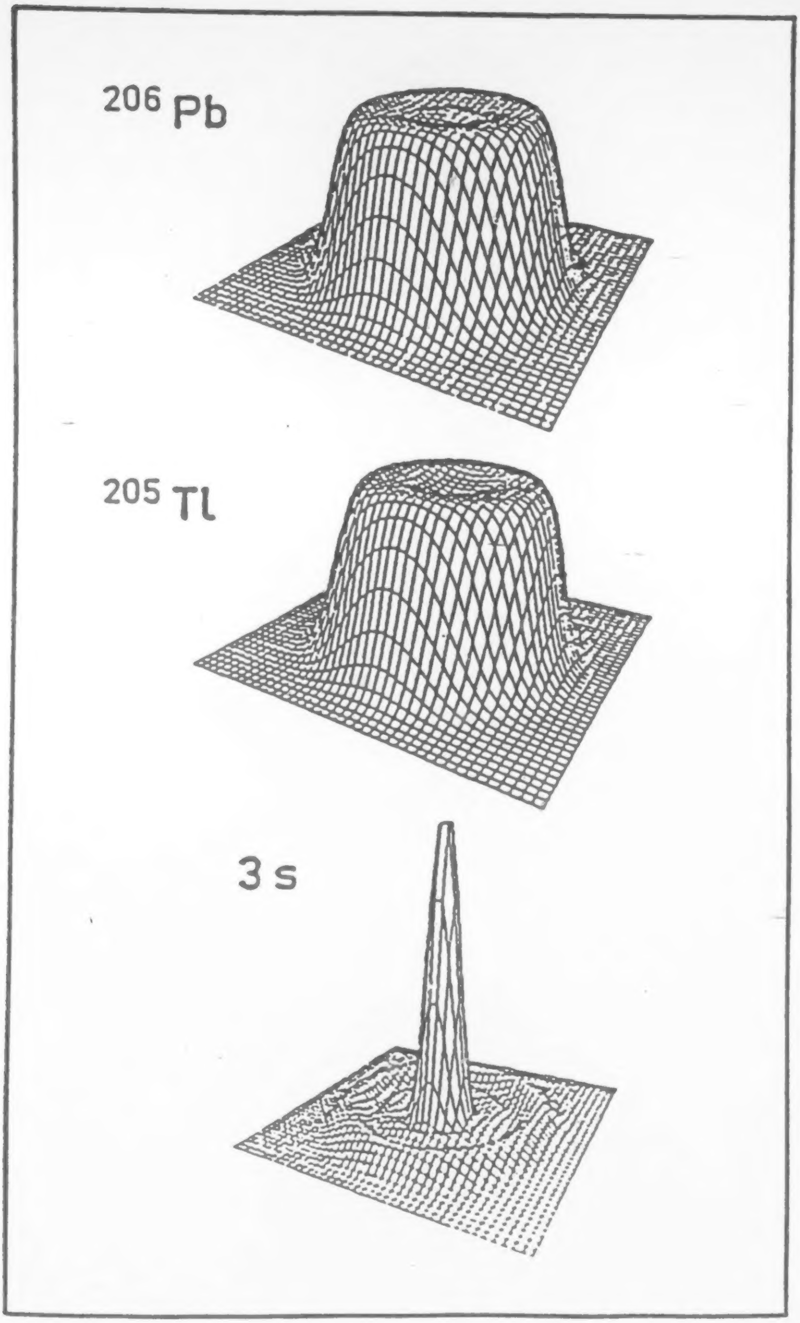
(a)-(h) : Projections of the experimental data

(i)-(l) : Monte Carlo calculations assuming two-body decay of a neutral particle

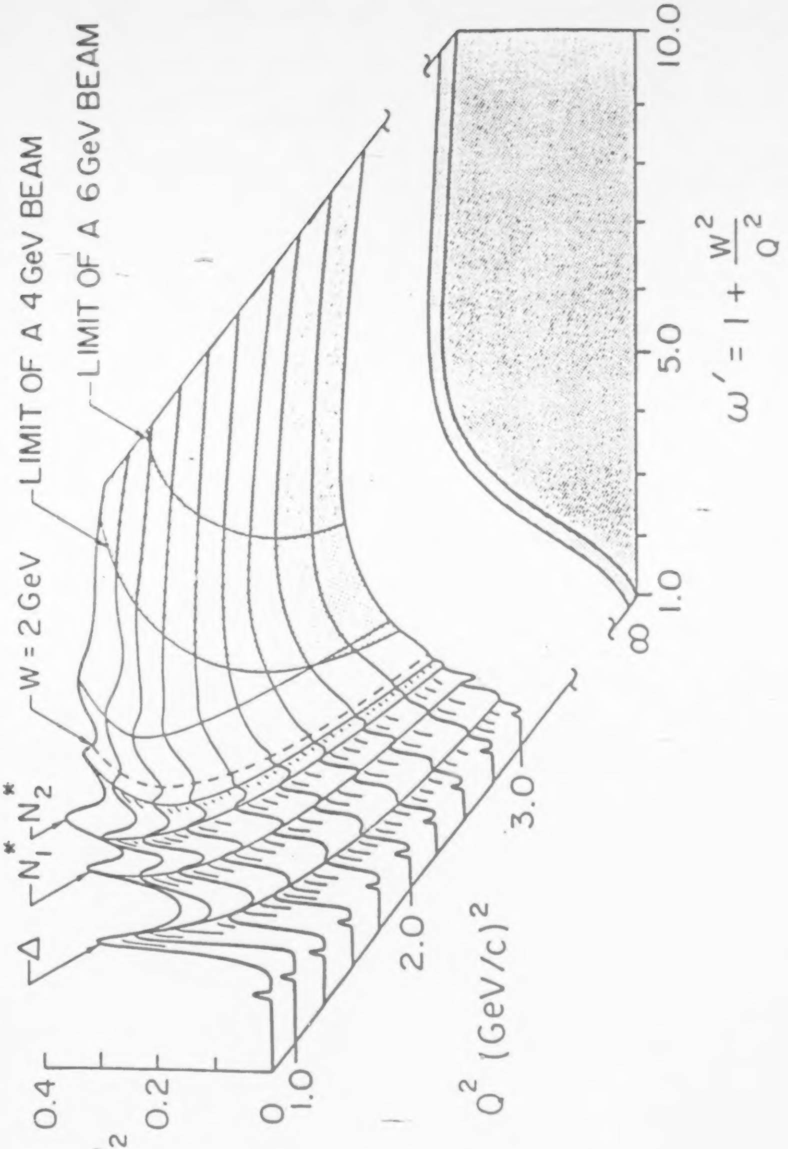
(m)-(p) : Monte Carlo calculations assuming internal pair conversion of a nuclear state

DATA OF COWAN et al. P.R.L. 56 444 (1986)

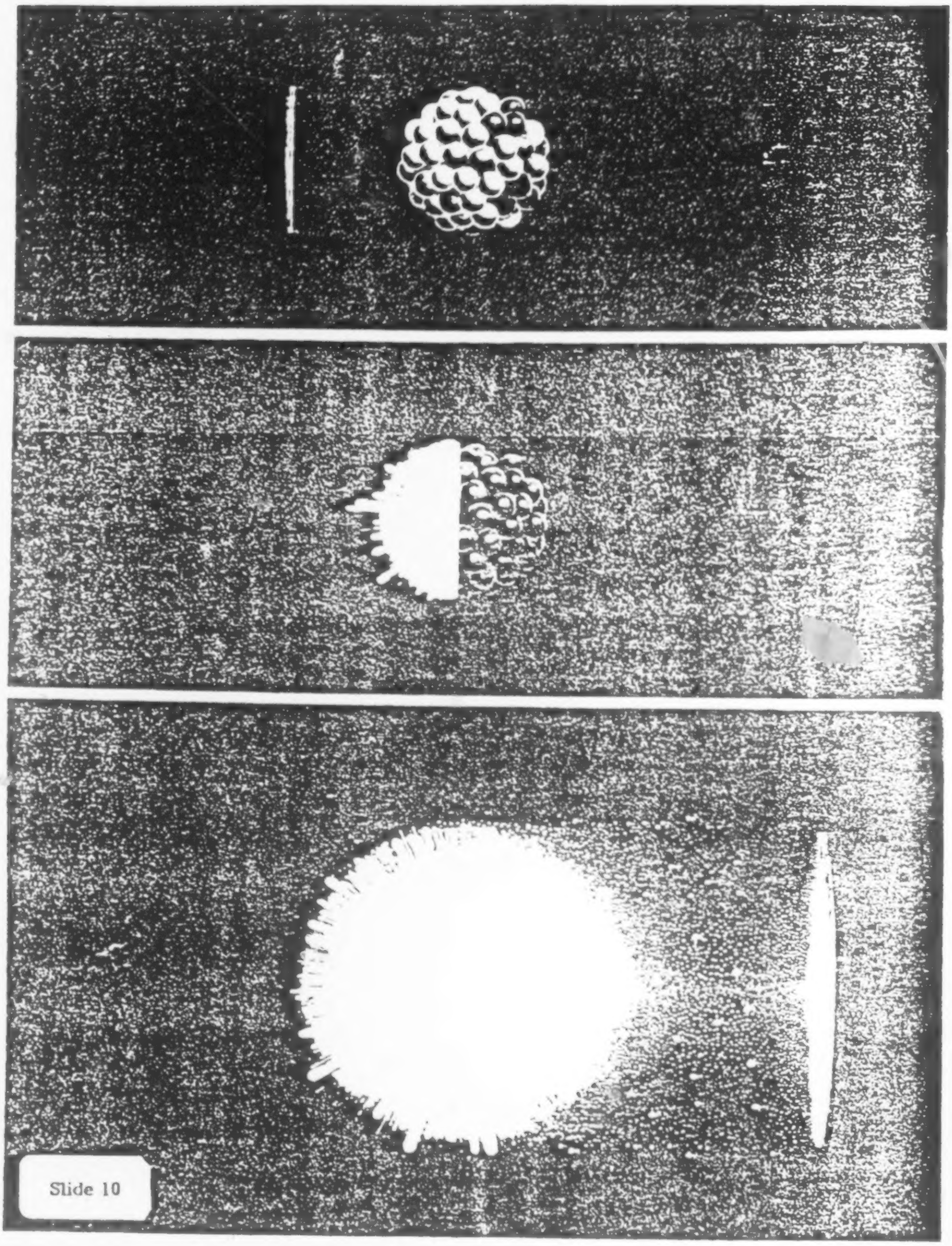
Slide 7



Slide 8


νW_2
0.4
0.2
0
1.0
2.0
3.0
Q^2 (GeV/c)^2
Δ
N_1^*
N_2^*
W = 2 GeV
LIMIT OF A 4 GeV BEAM
LIMIT OF A 6 GeV BEAM
∞
1.0
5.0
10.0
$\omega' = 1 + \frac{W^2}{Q^2}$

Slide 9



Slide 10

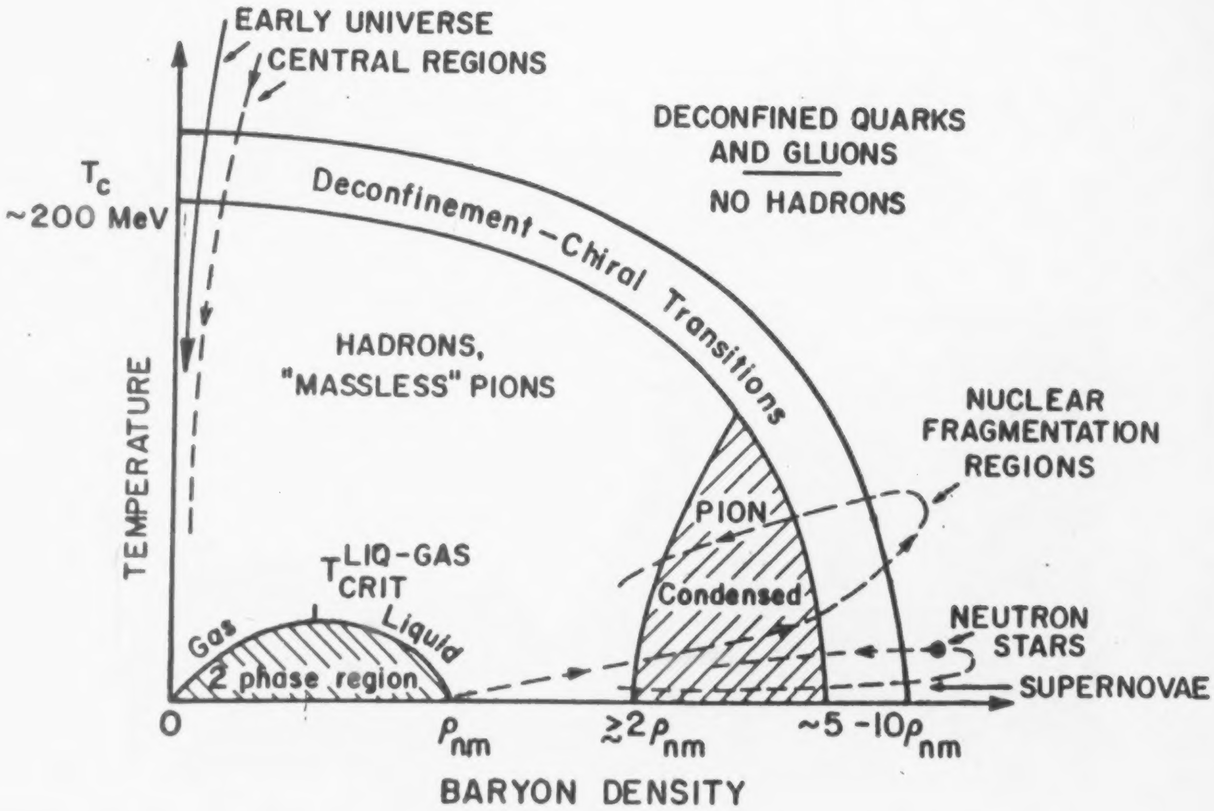
FUNDAMENTAL GOALS

A. PARTICLE PHYSICS

Deliver evermore energy to ever smaller volumes in hope of materializing at least some of it into entirely new particles ($m=E/c^2$)

B. RELATIVISTIC HEAVY ION PHYSICS

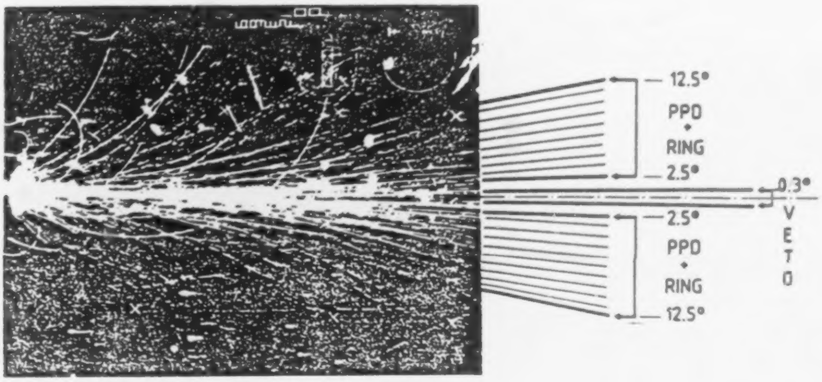
Deliver evermore energy to relatively large volumes (in nuclear terms) containing many neutrons and protons- hence many quarks and gluons-in hope of finding many body collective effects and an entirely new, fifth form of matter, the quark-gluon plasma

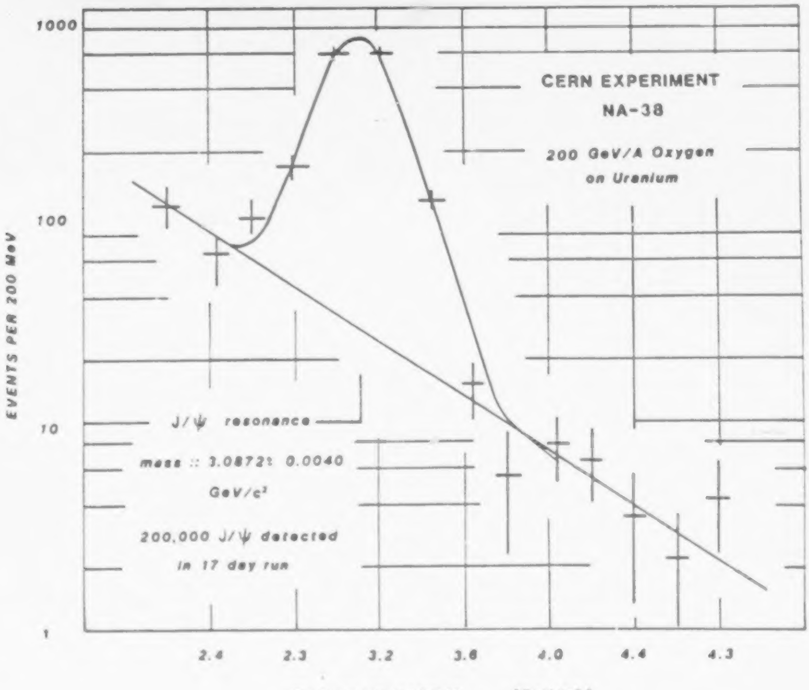

EARLY UNIVERSE
CENTRAL REGIONS
DECONFINED QUARKS AND GLUONS
NO HADRONS
T_c ~200 MeV
Deconfinement–Chiral Transitions
HADRONS, "MASSLESS" PIONS
TEMPERATURE
NUCLEAR FRAGMENTATION REGIONS
PION
Condensed
$T_{CRIT}^{LIQ-GAS}$
Gas
Liquid
2 phase region
NEUTRON STARS
SUPERNOVAE
0
ρ_{nm}
$\gtrsim 2\rho_{nm}$
$\sim 5-10\rho_{nm}$
BARYON DENSITY

Slide 12

ULTRA RELATIVISTIC HEAVY ION COLLISIONS

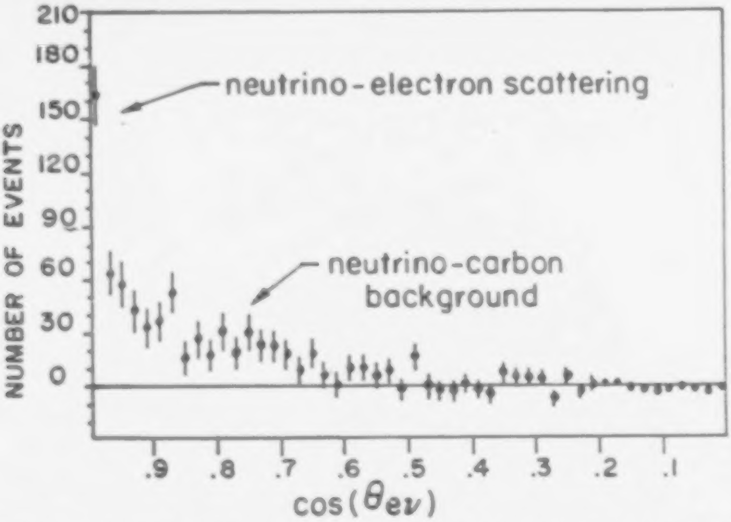
CERN EXPERIMENT NA-35 *200 GeV/A oxygen on lead*


12.5°
PPD
+
RING
2.5°
0.3°
2.5°
PPD
+
RING
12.5°
VETO



Slide 13

Neutrino-electron scattering produces recoil electrons in the forward direction. The experimental results show clearly this forward peak.



From the events in the forward peak, the experimenters extract the cross-section,

$$\sigma(\nu_e e^-, \mathrm{exp}) = 9.8 \pm 2.5\ E_\nu(\mathrm{GeV}) \times 10^{-42}\ \mathrm{cm}^2$$

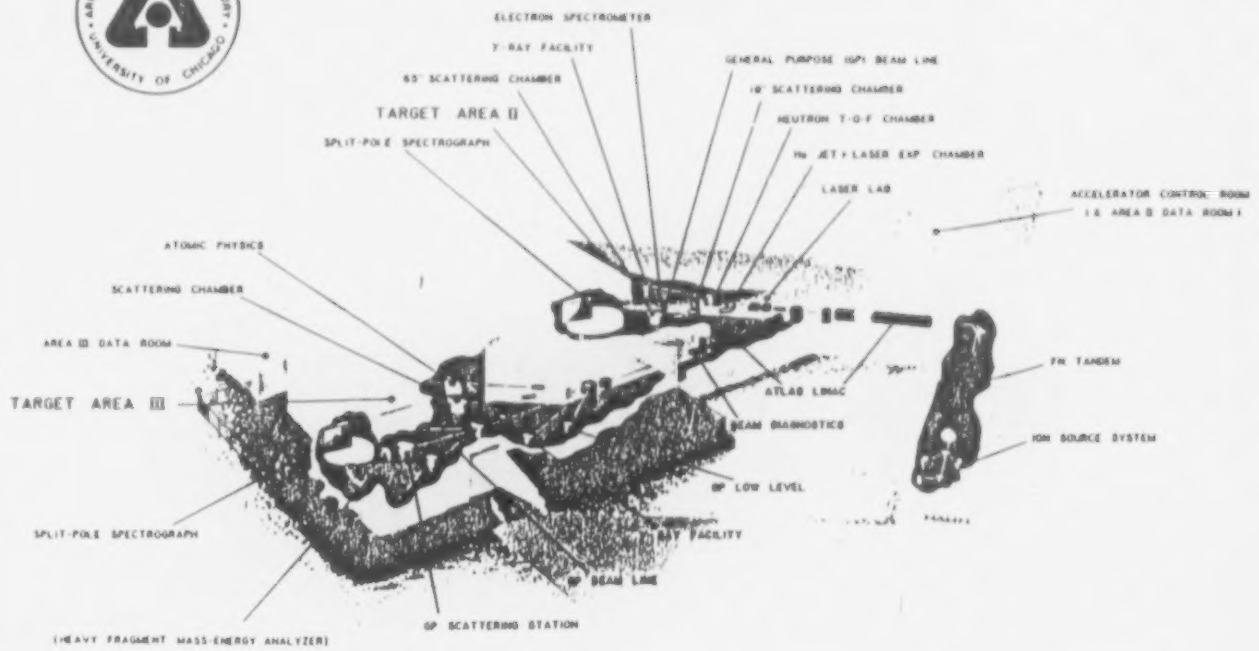
This agrees well with the standard model (WSG) prediction, which includes the W-Z interference,

$$\sigma(\nu_e e^-, \mathrm{theory}) = 9.2\ E_\nu\ (\mathrm{GeV}) \times 10^{-42}\ \mathrm{cm}^2$$

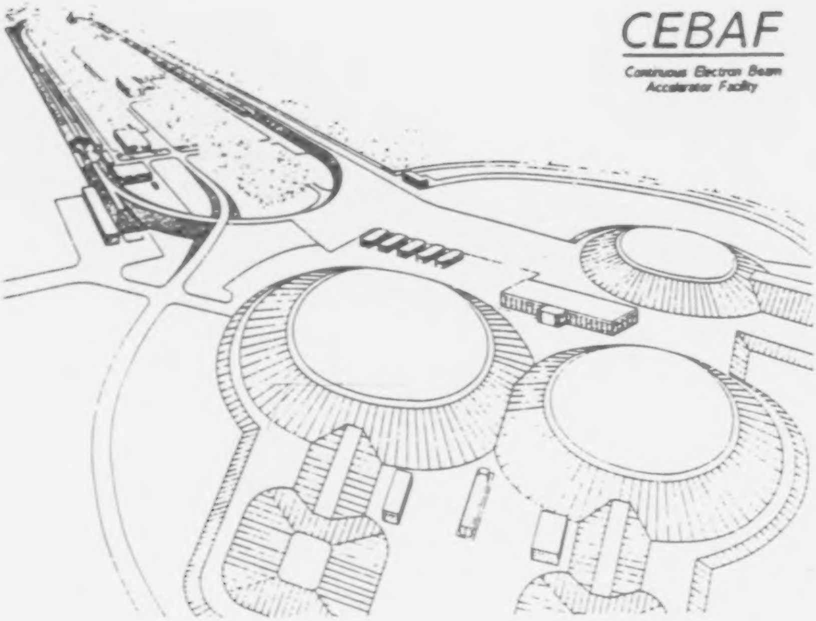
Experiment 225-Los Alamos Meson Physics Facility

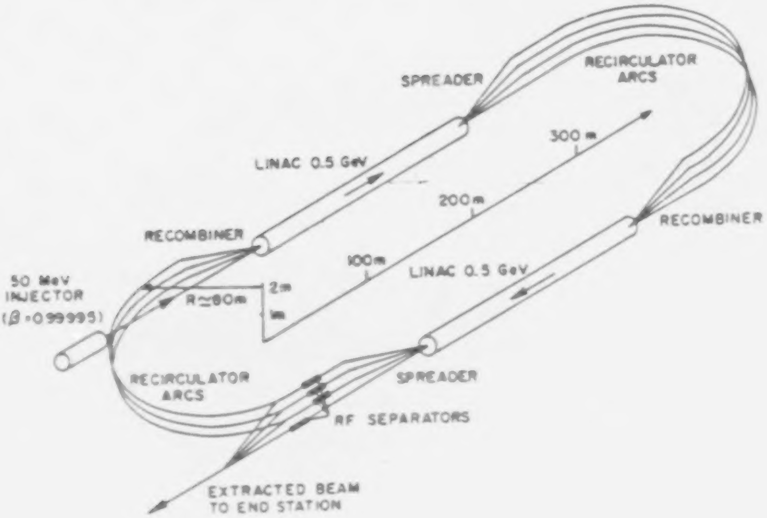
ARGONNE NATIONAL LABORATORY • UNIVERSITY OF CHICAGO

ATLAS

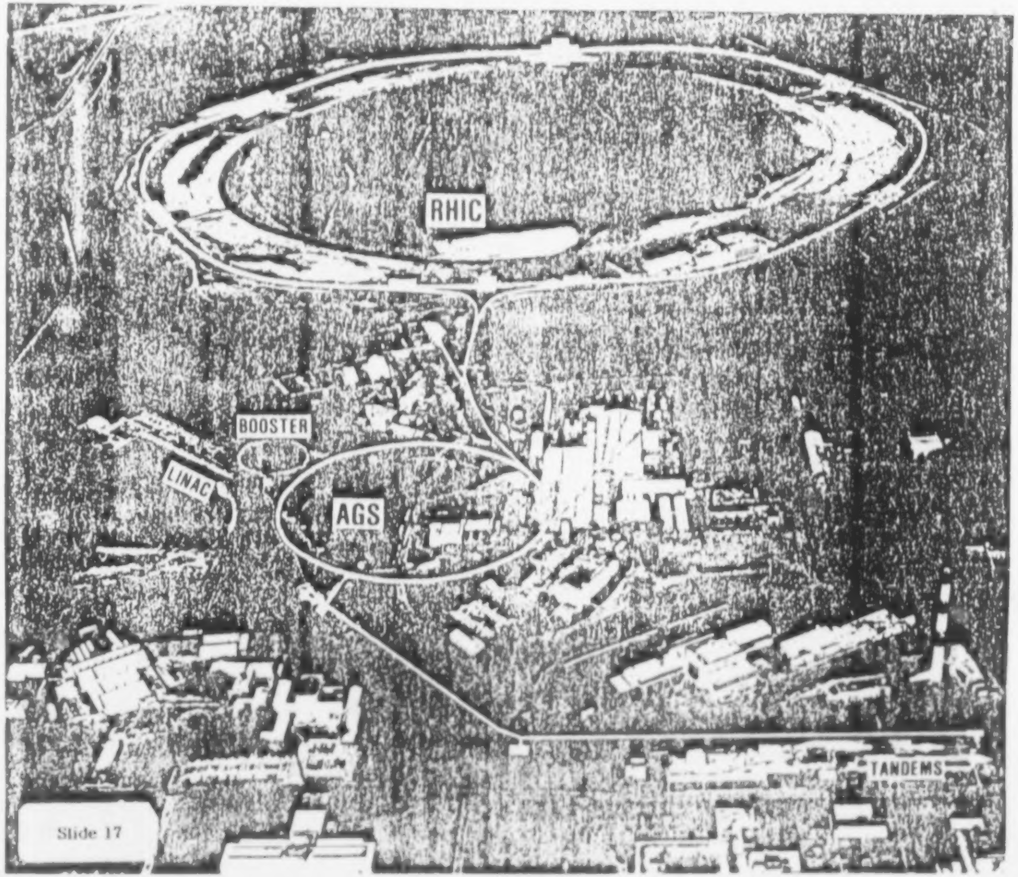

ELECTRON SPECTROMETER
γ-RAY FACILITY
65" SCATTERING CHAMBER
TARGET AREA II
SPLIT-POLE SPECTROGRAPH
GENERAL PURPOSE (GP) BEAM LINE
18" SCATTERING CHAMBER
NEUTRON T-O-F CHAMBER
He JET + LASER EXP CHAMBER
LASER LAB
ACCELERATOR CONTROL ROOM
(& AREA II DATA ROOM)
ATOMIC PHYSICS
SCATTERING CHAMBER
AREA III DATA ROOM
TARGET AREA III
FN TANDEM
ION SOURCE SYSTEM
ATLAS LINAC
BEAM DIAGNOSTICS
GP LOW LEVEL
RAY FACILITY
GP BEAM LINE
SPLIT-POLE SPECTROGRAPH
(HEAVY FRAGMENT MASS-ENERGY ANALYZER)
GP SCATTERING STATION

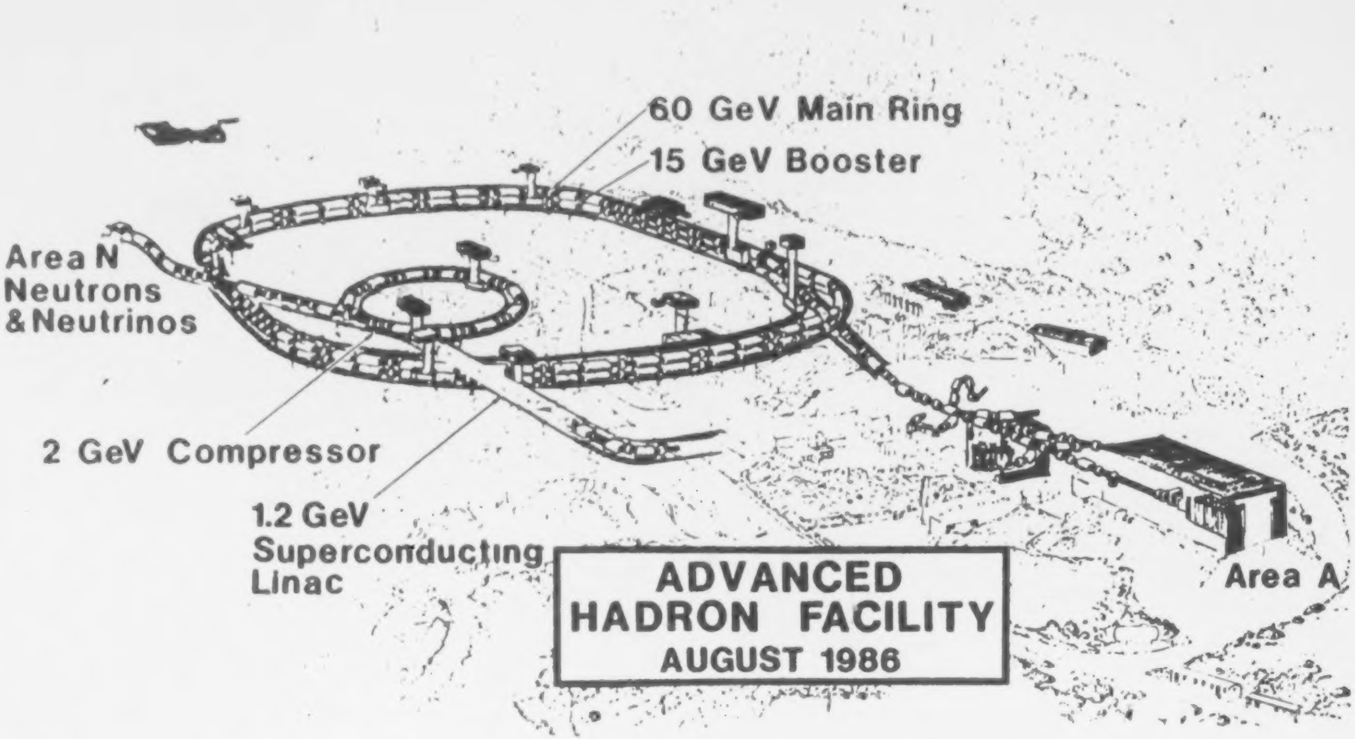
Slide 15


CEBAF
Continuous Electron Beam Accelerator Facility


SPREADER
RECIRCULATOR ARCS
300 m
LINAC 0.5 GeV
200 m
RECOMBINER
RECOMBINER
50 MeV INJECTOR (β=0.99995)
100m
LINAC 0.5 GeV
2m
R≃80m
1m
RECIRCULATOR ARCS
SPREADER
RF SEPARATORS
EXTRACTED BEAM TO END STATION

Slide 16

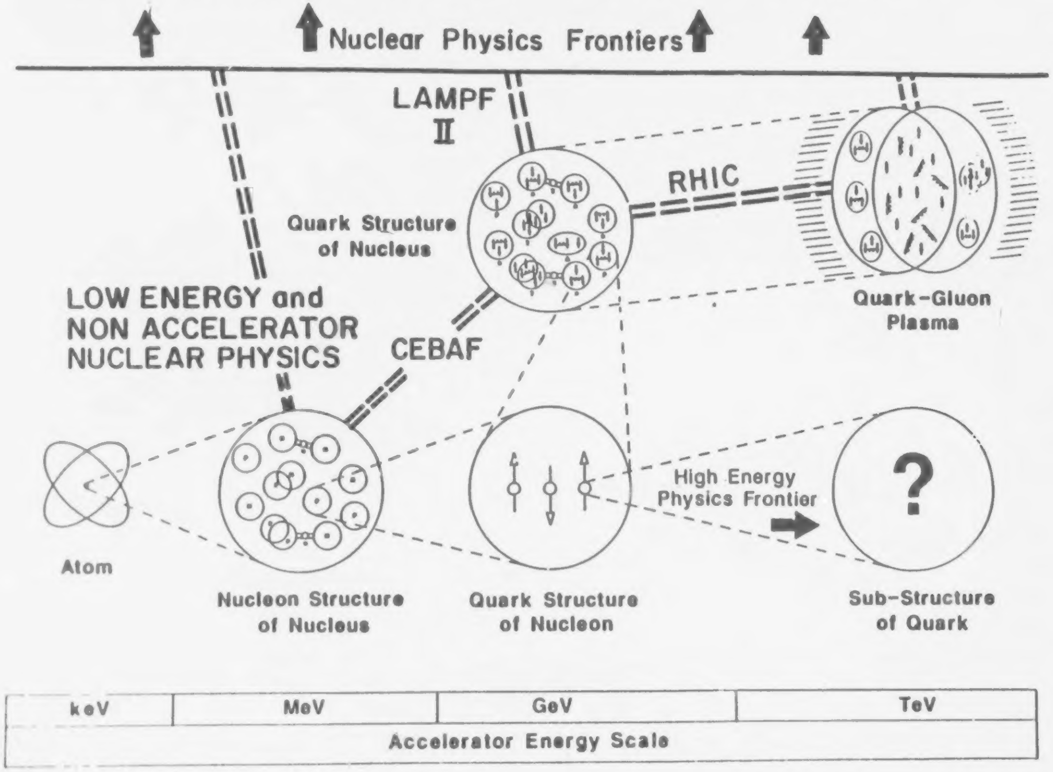

RHIC
BOOSTER
LINAC
AGS
TANDEMS
Slide 17


60 GeV Main Ring
15 GeV Booster
Area N
Neutrons
& Neutrinos
2 GeV Compressor
1.2 GeV
Superconducting
Linac
Area A

ADVANCED
HADRON FACILITY
AUGUST 1986

Slide 18

UNDERSTANDING THE STRUCTURE OF MATTER WITH QUANTUM CHROMODYNAMICS (QCD)



Nuclear Physics Frontiers

LAMPF II

RHIC

CEBAF

LOW ENERGY and
NON ACCELERATOR
NUCLEAR PHYSICS

Quark Structure of Nucleus

Quark-Gluon Plasma

Atom

Nucleon Structure of Nucleus

Quark Structure of Nucleon

High Energy Physics Frontier

Sub-Structure of Quark

keV	MeV	GeV	TeV
Accelerator Energy Scale			

Slide 19

US NUCLEAR PHYSICS FACILITIES

1969: 90 university based, accelerator based programs supported by NSF and AEC

1987: 5 university based accelerator based progerams supported by DOE and 11 by NSF

1987: EXISTING FACILITIES

Large tandem Van de Graeffs	*9*
Cyclotrons	*5*
Electron linacs	*3*
Neutron facilities	*4*
Proton linacs	*1*
Total	*22*

FUTURE FACILITIES

CEBAF (under construction)	*1*
RHIC (proposed)	*1*
LAMPF II (proposed)	*1*
OTHERS	*?*

SOCIETAL IMPACT OF NUCLEAR PHYSICS

- LONG HISTORY OF DEVELOPMENT OF NEW TECHNIQUES

  High power radio-frequency systems
  Large high vacuum systems
  Electronic pulse circuitry
  Transistorized electronic systems
  Ion implantation-ion beam mixing
  Nuclear clocks: 10^{-23} sec-10^{15}sec

- NUCLEAR ENERGY

  Nuclear fission systems
  Nuclear fusion systems
  Small radioactive energy sources
  Military applications

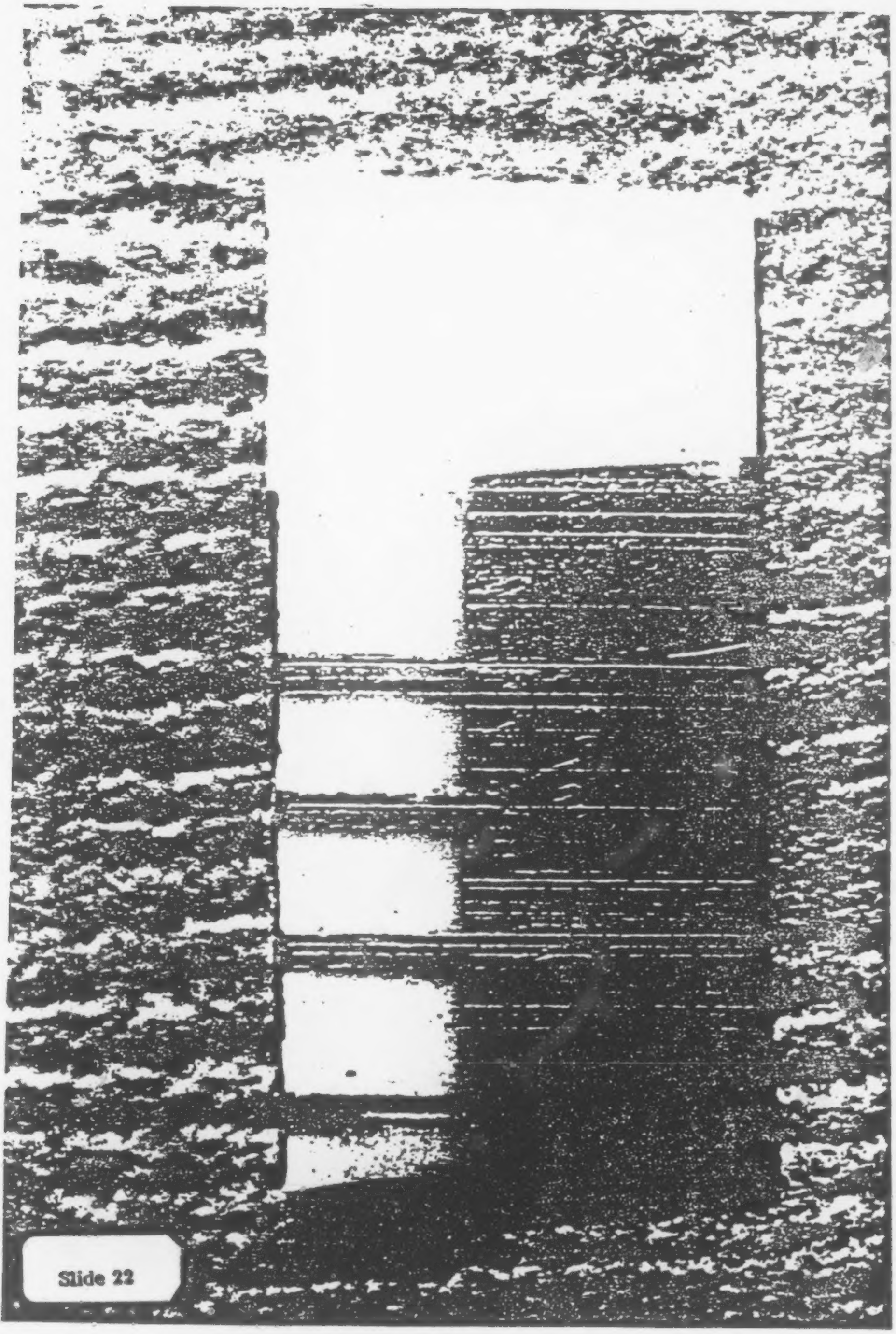
- NUCLEAR MEDICINE

  Tailored radioisotopes
  Imaging technologies - PET, NMR etc.
  Research and clinical technologies
  Gamma ray and electron sterilization

- ENVIRONMENTAL SCIENCE

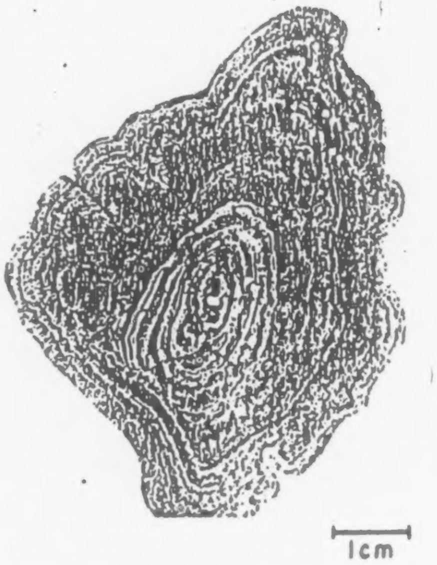
  Detectors, sensors, detection systems.

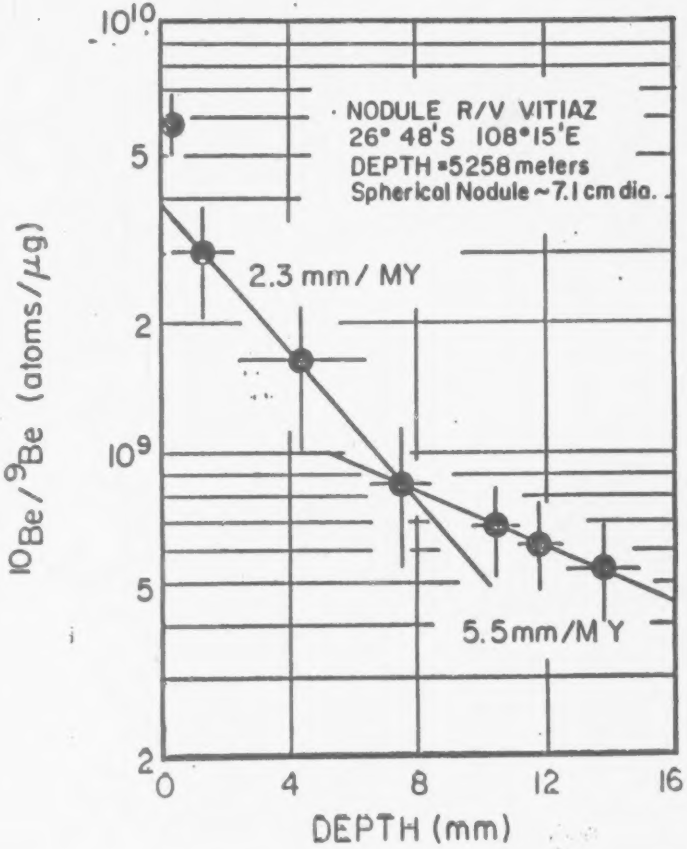
Slide 21



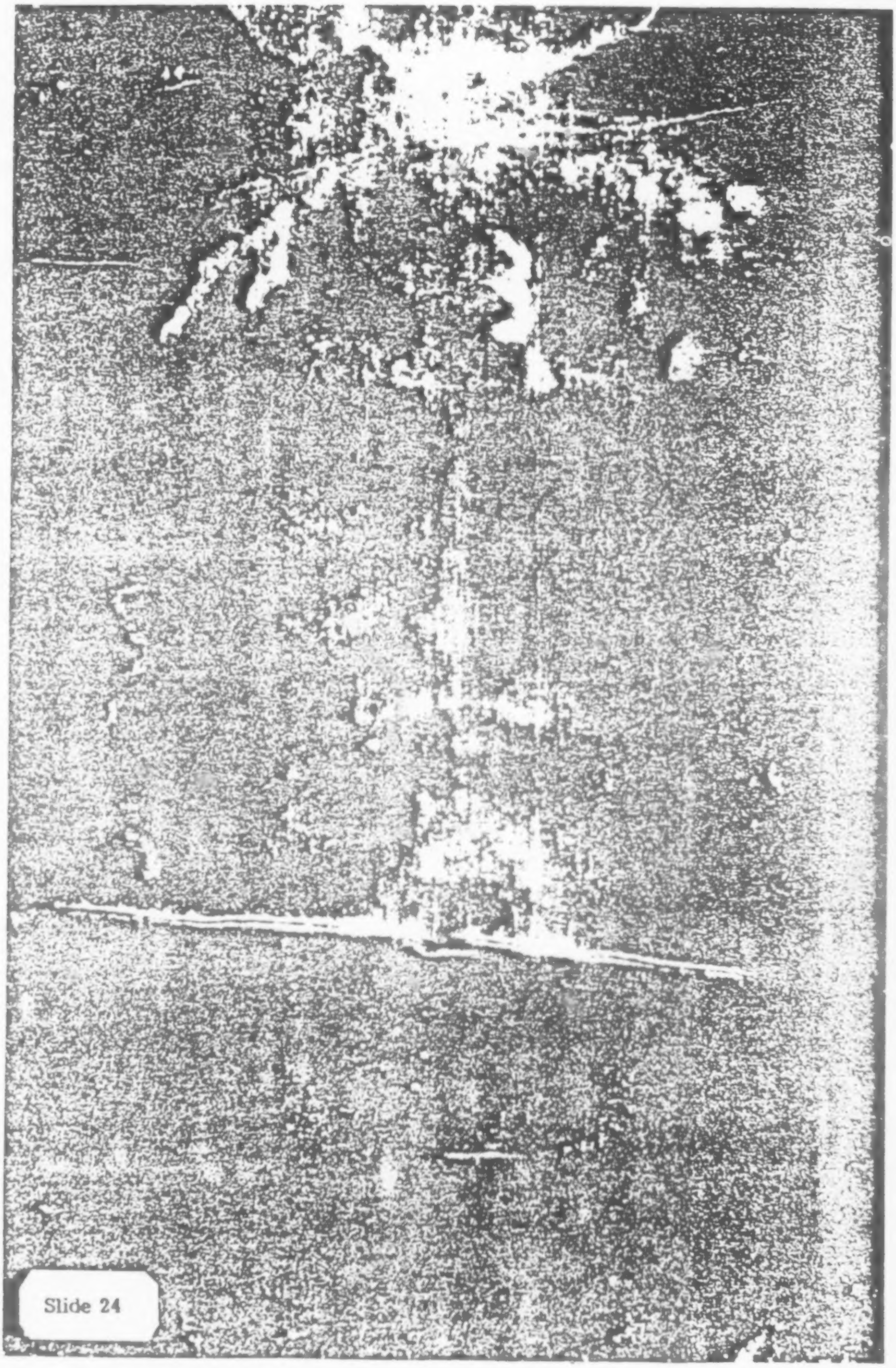
Slide 22

ACCELERATOR MASS SPECTROMETRY



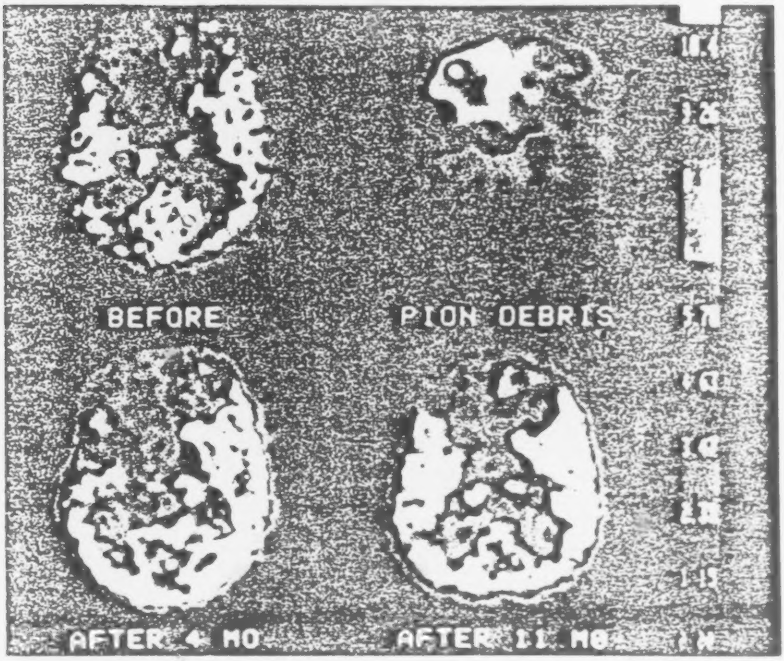


Slide 23


Slide 24

UBC/TRIUMF POSITRON EMISSION TOMOGRAPHY PROGRAM

Brian Pate et al ., Vancouver


BEFORE
PION DEBRIS
AFTER 4 MO
AFTER 11 MO

Top left: May 1985, before treatment of glioblastoma in brain

Top right: May 1985, after irradiation with pion beams stopping in tumor

Bottom left: September 1985 - tumor shrinking

Bottom right: April 1986 - tumor essentially gone - brain function restored

Slide 25

MUON CATALYZED FUSION

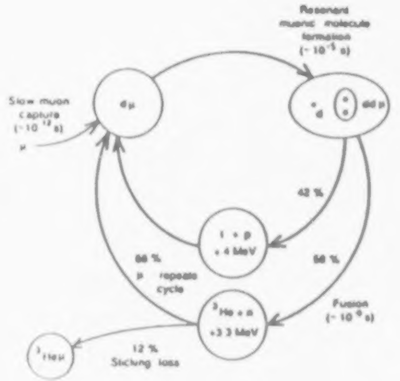
Steven Jones, Brigham Young University and Los Alamos

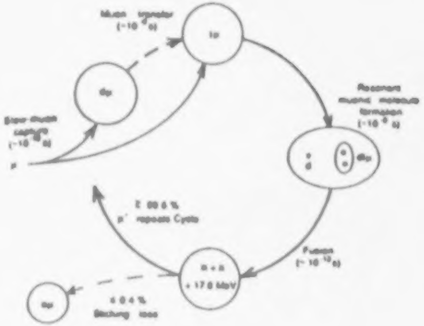
$$d+d \longrightarrow \begin{matrix} t+p & 4.0\ \text{MeV} \\ h+n & 3.3\ \text{MeV} \end{matrix}$$

$$d+t \longrightarrow \alpha + n + 17.6\ \text{MeV}$$

Current 1987 status at LASL

-150 fusions per muon)


Slow muon capture
(~10^{-12} s)
μ
dμ
Resonant muonic molecule formation
(~10^{-5} s)
d
ddμ
42 %
58 %
t + p
+ 4 MeV
88 %
μ repeats cycle
^{3}He + n
+3.3 MeV
Fusion
(~10^{-9} s)
12 %
Sticking loss
^{3}Heμ


Muon transfer
(~10^{-8} s)
tμ
dμ
Slow muon capture
(~10^{-12} s)
μ
Resonant muonic molecule formation
(~10^{-8} s)
d
dtμ
≥ 99.6 %
μ$^-$ repeats Cycle
Fusion
(~10^{-12} s)
α + n
+ 17.6 MeV
≤ 0.4 %
Sticking loss
αμ

Luis Alvarez et al. Phys Rev 105 1127 (1957)

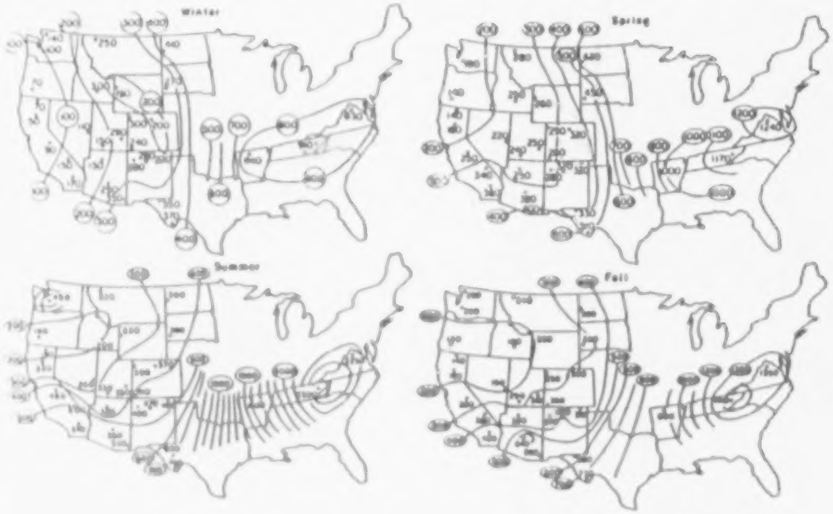
Va. B. Zeldovich, Doke. Acad. Nauk. 95 493 (1954)

E.A. Vesman , Zh. eksp. teor. Fiz. Pisma Redapt. 5 113 (1967)

ENVIRONMENTAL STUDIES

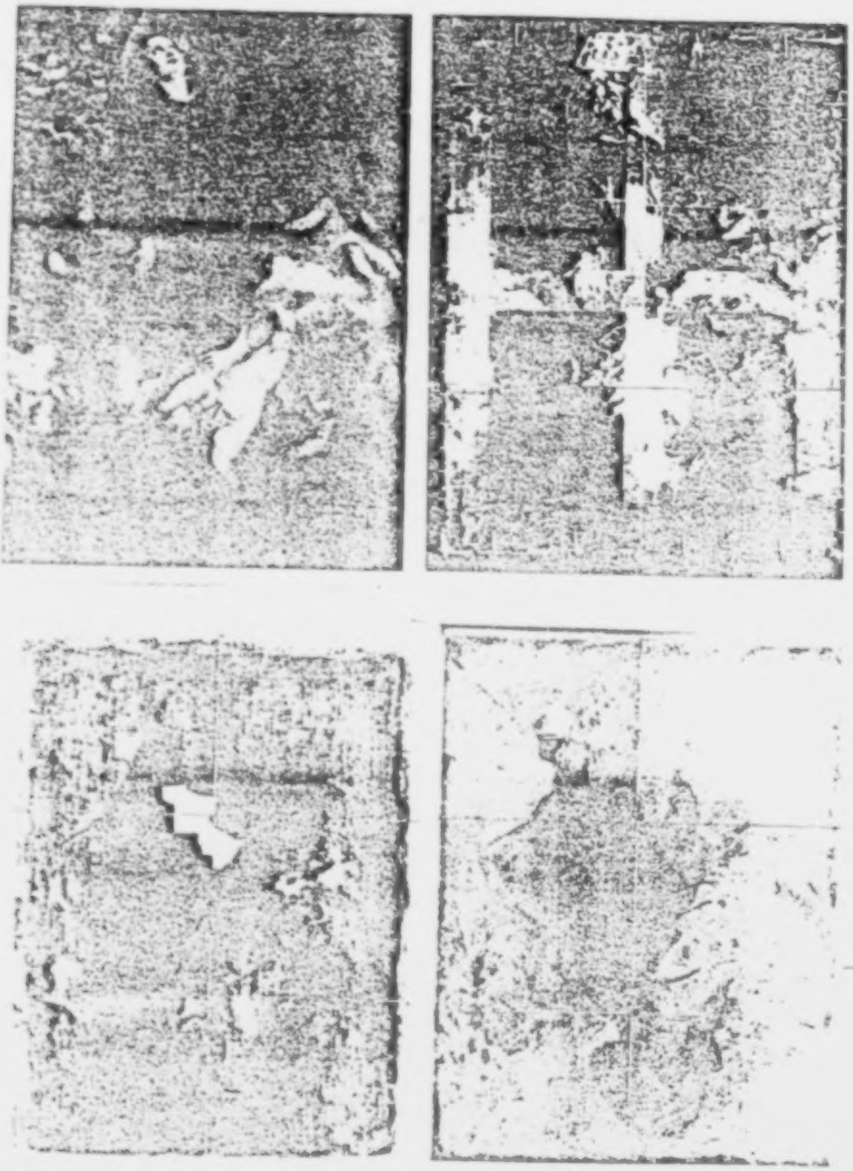
Thomas Cabill et al. University of California, Davis

Proton induced x-ray emission (PIXIE) at Crocker Cyclotron



Seasonal measurements of fine sulphur concentrations in ng/m³ during the period June 1982 to February 1985

Slide 27



Slide 28

THE PEOPLE OF NUCLEAR PHYSICS

- REQUIRE EXPERIENCE IN BROAD RANGE OF TECHNIQUES

  Electronics, vacuum, thin films,
  detector technology, computers,
  high power radio frequency

- REQUIRE SYSTEMS APPROACH

  Progress comes only from cooperative
  efforts of engineers, technicians,
  other scientists, and colleagues

- CONFIDENCE IN ATTACKING BROAD UNSTRUCTURED PROBLEMS

  Makes those trained in nuclear physics,
  able partners in search for solutions to
  major societal and industrial problems

- NUCLEAR PHYSICS SELECTED FOR EMPHASIS IN LEADING DEVELOPED COUNTRIES

  France, Italy, Germany, Japan,
  United Kingdom

Slide 29

DISCUSSION

Mr. **Stallings**. Thank you, Dr. Bromley, for excellent testimony. I appreciate your enthusiasm and your commitment to your profession.

Would you comment for just a moment on the importance you see in the upgrades of the university facilities, such as the Bates MIT accelerator and the BEVALAC, at Berkeley, the Holifield, too, at Oak Ridge.

Dr. **Bromley**. All of these, Mr. Chairman, are extremely important. There is no question but what the development of university-based facilities has a very definite impact on the attraction of young people into the field and their training, no question.

It is also true that as we move to the very highest energy frontiers, as I have discussed with you this morning, that there is a tendency to leapfrog areas that are rife with good physics, that are appropriate in size and scope for university campuses and so I am delighted to see, for example, the start being made at Bates on this work.

I think that there is clearly excellent physics to be done with the BEVALAC upgrade, as emphasized by the Vogt Committee, but I must also say, Mr. Chairman, that we in the field recognize as you do that the resources in the community and the resources available to nuclear physics are limited, and so we have to make often very difficult decisions about where to put those resources, and that is why the NSAC long-range plan is so important, because it gives us the stability and the basis for planning. So at the moment the highest priority goes to getting RHIC started, despite the fact that there is much great physics to be done with the BEVALAC upgrade, for example. That upgrade has a lower priority in the minds of the community.

The same is true of the upgraded Holifield, even though it is terribly important. I wish I could sit here and say that we should do all of them, but it is simply—in my belief—only responsible on our part to try to give you what we believe to be the highest priorities in terms of the greatest amount of new research for a given investment in the facility.

Mr. **Stallings**. Thank you, Dr. Bromley.

Mr. Morrison?

Mr. **Morrison**. Doctor, I really respect the information that you have presented to us. I have to admit my relief when you said you don't have to worry about the details and I couldn't help but smile a little when you talked about the dying seconds of a collapsing star as in its relationship with the Presidential races that are going on. [Laughter.]

My question, I think a basic question is very similar to the Chairman's, and that is one of the Presidential initiatives which we are wrestling with in this Committee is the Superconducting Super Collider, and I guess the basic thrust of what you are saying is that maybe the dramatic progress we in fact are making are through the smaller university based facilities as opposed to a tremendous expenditure of funds that we don't have in one concentrated area.

Is there a direct conflict there within the scientific community?

Dr. **Bromley**. I don't think as much as the media would have us believe, sir. I believe there is a recognition both in my field and in particle physics, and, in fact, throughout all of fundamental science, that we make progress by an orderly advance along a very broad frontier. There is no question but what university facilities play a very important role in attracting the new generation of young scientists. That is a crucial role that has to be emphasized.

But then what we require, if we are going to be competitive in the world approach to fundamental science, is a spectrum of facilities that cover a broad range of size and scope.

Now my colleagues in particle physics at the moment maintain that their frontier is at the very highest energies that SSC would give them. The hope, as I mentioned, to put ever more energy into ever smaller volumes to materialize for study particles that have never been seen before, to test their understanding of the most fundamental behavior of the matter and the forces that make up our universe. They have had enough tantalizing information with their existing facilities, like the Tevatron, for example, to lead them to believe that the SSC would give them access to a whole new range of phenomenon. But the decision that you face, of course, is a much broader and more difficult one, and that is that you have to weigh these claims and the costs of such a facility against all the other claims and the benefits that would flow from expenditures elsewhere, and that is the problem that all of us face, that we are in a time when we all recognize that resources are limited.

So I would not say at all that the university facilities are more important than the very large facilities. I would emphasize that they are complementary and in fact, gentlemen, only you in the Congress can really make the decision as to how far towards the farthest frontiers we could go at any given time.

Mr. **Morrison**. I was afraid that you were going to say that; but I am very impressed.

Do you sense that we are still wrestling with trying to create the fusion reaction and then harness it in some way and now what I sense you are saying to us—that you are going way beyond that with potential sources of energy that really reflect maybe the beginning of the universe as we know it.

Do you sense in that investigation that there is the potential out there for something easier to harness and to utilize for the good of mankind than what we may be working on now?

Dr. **Bromley**. I wish I was able to answer you, but this is the purest of pure research and if I knew what was lurking out beyond that transition, of course, it would no longer be basic research and the thing about what we are doing is that no one can tell at what time, what place and in what magnitude the rewards will be. All we can tell you at this point is that those rewards have always been there in the past. I frankly can't answer your question. I can tell you that I personally believe that there is a very good possibility that we will find new kinds of matter, that we will find new ways to liberate energy, but it would be totally irresponsible for me to say that there is a possibility that they will be easier to achieve than fusion.

I think we must bear in mind that we were very lucky in the case of nuclear fission. If you simply make a big enough pile of graphite and uranium, you start getting energy out. The fusion problem, where you have to subject the fuel to 22 million pounds per square inch and at the same time raise it to 100 million degrees, results in engineering difficulties, and we haven't quite understood exactly how to handle those yet. It is a great challenge but it's off a piece.

Mr. **Morrison**. I was impressed with a quote that I would like to have as part of the record. In fact, it is your written testimony quoting Al Trivelpiece, who we miss very much, by the way, Mr. Chairman, where Dr. Trivelpiece says one-third of our current Gross National Product can be traced to better knowledge of the atom and I think what Dr. Bromley is sharing with us—that what he's talking about are realistic investments in even a greater knowledge of that atom.

Thank you, Mr. Chairman.

Mr. **Stallings**. Mr. Fawell?

Mr. **Fawell**. Thank you, Mr. Chairman. You had mentioned that one of the problems that you had with the new budget is that although it is generous, and we have heard this story before, then one goes on to say "but"—and that is understandable, that increasingly the best graduates want to come to work in the nuclear physics field, I believe you said, and your problem was because of the inadequacy of funds you are turning away these students. I assume this is probably true in other fields.

But approximately how many graduate students are there studying in nuclear physics now would you say, and about what proportion of these are foreign nationals?

Dr. **Bromley**. Well, let me begin with my own laboratory. It is one of the larger training centers. We have at the moment 30 graduate students in residence in the laboratory and of those 70 percent are American-born. In the entire country, I don't have the exact figures, sir—I will get them for you—as to the total number, but I would say that certainly more than 50 percent are American born.

Mr. **Fawell**. One gets the feeling that there are increasingly the foreign nationals and that we are somehow ignoring our own students, which probably isn't so. We have to excite them, and maybe we haven't done a good job in that regard.

Dr. **Bromley**. But if I may, sir, I think that there are about three answers to that question. The first is that the problem is not that there are too many foreign students; the problem is that there are too few American students in field after field. Engineering is a particularly good example.

The second point is that the difficulty does not arise at the college and university level, it arises much earlier in the system, back in the pre-high school and the high school areas where not enough young people are attracted into these fields or given the preparation to allow them to build careers in them.

But the difficulty that I see for us is that the educational pipeline is well defined. We know how many people are in it right now and we see frightening shortages developing in the early 1990's. Erich Bloch I'm sure has testified before you as to the level of shortages we are talking about in the early 1990's; 200,000 American students received their bachelor's degree last year. Five years from now that number will have dropped to less than 150,000. That is a dramatic drop in five years, and we know that there is nothing we can do about that, because the students are still in the pipeline. So, what we have to do is to identify our bright young students earlier, try to support them, try to identify them and make sure that they get all the education they can take.

You may recall that Dave Packard and I generated a report for the White House Science Council about a year ago in which this was one of our major recommendations.

Mr. **Fawell**. But apparently you do think you have inadequate funds to even find positions for those who are standing in line?

Dr. **Bromley**. That is absolutely true, sir. We at the moment do not have the funds. As you well recognize, with large facilities of the kind I have been talking about, it takes a large fraction of the total research budget simply to keep the doors open, to keep the lights on, and the heat going. So that the fraction of your total budget that is available to do research and to support graduate students is a tiny fraction of that total.

We are at the situation across the country—the universities like University of Washington, Seattle; Texas A&M; Rochester; Princeton—you name them—MIT, where more young people who have managed to get through the hurdles we have in our system, managed to get through to graduate school and want to work in our field simply are not being allowed to do it because we can't afford to support them.

Mr. **Fawell**. Are we attracting women as much we ought to? I recall a conversation at the University of Chicago several years ago where it was felt that somehow this country was not attracting young ladies into the science fields as we ought to do, and often times with our immigration from Europe, we have had the first-generation children going into the science fields and then after that they became Americanized and want to make money.

Are we attracting minorities?

Dr. **Bromley**. Sir, I can only say that the situation in the sciences and to a large degree in engineering in this country can only be classed as scandalous when it comes to our attraction of women and minorities. The fraction of women in the physics community, for example, is certainly less than 10 percent. The fraction of minorities is probably less than 1 percent and there are two ways to really work on that problem.

In my own laboratory, for example, we are trying to maintain something approaching a third of our graduate students as females, which means that in the competition for positions females fair very well compared to males. It is also true that we must somehow manage to make our high school education much less of a hurdle for females in technical and scientific fields. It is ridiculous that in this day and age, with the needs that we face for people trained in science and technology, to have high school teachers tell female students that mathematics is not for you—that science is not for you, and in droves we turn our female students away from engineering and science. That is where it happens, not from the colleges.

Mr. **Fawell**. Thank you.

Mr. Stallings. Again, Dr. Bromley, thank you for that excellent testimony and your responsiveness to our questions. You have given this Committee a great deal to think about.

Dr. Bromley. Thank you, sir.

Panel 1: X-Ray Lithography

Mr. Stallings. Our next three witnesses appear as a panel.

Paul Reardon is from Science Applications International Corporation. Dr. Tom Dillon will be giving his testimony. They will speak for the x-ray Lithography Consortium. Dr. Michael Knotek is Director of the National Synchrotron Light Source at Brookhaven National Laboratory, and Dr. David L. Huber is Director of the Synchrotron Radiation Center from the University of Wisconsin-Madison.

Gentlemen, I welcome you to the Subcommittee. Your written statements will be made part of the record. Please summarize them or proceed as you wish.

Dr. Dillon.

STATEMENT OF DR. THOMAS DILLON, SENIOR VICE PRESIDENT, SCIENCE APPLICATIONS INTERNATIONAL CORPORATION, SAN DIEGO, CA

Dr. Dillon. Thank you very much, Mr. Chairman. It is certainly a pleasure to appear before the Subcommittee on Energy R&D. I have the privilege here of not only representing SAIC but, in fact, an industrial partnership of General Atomics, Bechtel and SAIC, and the remarks that I am going to give really reflect the spirit of all three companies.

We do support the x-ray lithography initiative that the Subcommittee launched with the fiscal year 1988 budget. To make the point right up in front, we will be recommending a continuation of that thrust and that initiative, and particularly with regard to the funding during the fiscal year 1989 budget.

I want to report briefly on our response to your initiative by the team, and not only an industrial team but also close working relationships we have had with both Brookhaven National Laboratory and the University of Wisconsin.

It seemed to us as these discussions took place over the past year that this is a true national imperative. When you look at both issues of commercial competitiveness as well as national security concerns, that the United States should accept nothing less than a preeminent position in the area of chip manufacturing with feature sizes at the half-micron and lower, particularly when there is some thought that a technology may make feature sizes as small as a tenth of a micron possible.

It also seemed to us that it was a classic case where decades of technology development reposed in Federally-funded laboratories. The Nation needs a timely, effective and economical technology transfer into an industrial framework. So last year's initiative triggered SAIC, General Atomics and Bechtel to form a partnership pooling our resources, both financial resources as well as human resources, to support and respond to what we believe is an emerging national program.

Specifically, the team is responding to all four major facets of the national program. We see them as the provision of additional x-ray beam lines, provision for a commercial generation light source, requirements and layout for a pilot manufacturing plant, and finally, R&D on superconducting magnets.

Although the initiative is really not more than about four-months old at this time, I think there is some progress. This is a proposal that we had intended to submit to Louisiana State University yesterday. It is my understanding—I have not been able to confirm it—that some details associated with the contracting led to some delay on this, but the process, I think, is interesting.

We will be using design approaches developed for Aladdin at the Synchrotron Radiation Center at the University of Wisconsin. In circular sections this facility comes close to a state-of-the-art model for a synchrotron-based x-ray lithography system with commercial potential. The project, of course, cannot be completed without additional funding in fiscal year 1989.

The SAIC team at its own expense is also working with the University of Wisconsin in order to understand the x-ray lithography experimental program being run in Aladdin in order to assist LSU and others in the provision of beam lines at a later stage in the program.

With regard to construction of a synchrotron light source of advanced design at Brookhaven, in fiscal year 1988 one of the initial steps envisioned for the development of a commercial synchrotron light source was to build at Brookhaven a light source specifically designed to meet the x-ray beam requirements for a commercial x-ray lithography facility. The team has met with Brookhaven and presented its capabilities for designing and building a synchrotron light source of advanced design.

We believe that BNL's industrial partner, whoever it will be, should be chosen for the design and construction of a new light source facility and be given significant design, fabrication, management and commissioning responsibilities as opposed to purely engineering assistance. That is critical in order to really assure effective technology transfer.

This effort really needs to be much more fully funded in fiscal year 1989 if the overall goal of a commercialization feasibility within five years is to be achieved.

With regard to pilot-manufacturing plant layout and requirements, the team is fully prepared to develop a commercialization plan and preconceptual design of a facility on a cost-sharing basis, provided that the programs that I have just mentioned are able to go forward and generate a data base from which a commercial plant preconceptual design can be developed, and that the chip manufacturers and their customers are committed to downstream use of this technology.

SAIC would be willing to reimburse the Federal Government and/or the laboratories and the institutions which develop the designs on a mutually agreeable royalty basis.

Finally, with regard to R&D on superconducting magnet design, the SAIC team, particularly through our partner, General Atomics, which has deep experience in the design and fabrication of superconducting magnet systems, is prepared to undertake superconducting magnet prototype R&D work.

Our industrial team is looking forward to forging a broader partnership with the national labs, universities, the Administration and the Congress to ensure that the country's talent is effectively focused on this exciting challenge. We applaud the Congress for their leadership and bold action on this program and assure you that we at SAIC, GA and Bechtel will do our best to provide the industrialization effort you envisioned in a timely and effective manner.

I want to thank you for your attention and thank you for giving the team this opportunity to speak to you about the important program that you now have underway. Thank you.

[The prepared statement of Mr. Reardon follows:]

TESTIMONY BEFORE U.S. HOUSE OF CONGRESS
SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

PROPOSED SAIC INDUSTRIAL INVOLVEMENT IN U.S. X-RAY LITHOGRAPHY

By:

PAUL J. REARDON, Vice President and
Director of Experimental Projects
Science Applications International Corporation

March 29, 1988

TESTIMONY BEFORE U.S. HOUSE OF CONGRESS SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

PROPOSED SAIC INDUSTRIAL INVOLVEMENT IN U.S. X-RAY LITHOGRAPHY

It is a pleasure for me to address the Subcommittee on Energy Research and Development on the subject of private sector involvement in U.S. X-Ray Lithography. U.S. industry is aware of and congratulates you on the congressional initiatives taken to ensure that timely and effective action is taken to guarantee that the U.S. does not continue to fall behind other nations in developing this approach to the provision of sub-micron chips for advanced electronics systems. The integrated circuits made possible by the production of chips in the 0.1 to 0.5 micron ranges will shortly become a requirement in the provision of advanced complex communication and computation systems that involve large memory capacity (16-256 Megabit) with very high access speeds. These new electronic systems are a vital component of the advanced computation and communication systems needed for competitive commercial applications. In addition, they are required for the upgrading and modernization of many defense information and application systems. The U.S. and its industry cannot let the initiative for synchrotron produced x-ray lithography reside mainly in the Western European and Pacific Rim nations. For economic competitiveness and defense, we must develop this industrial capability here in the U.S. as soon as possible.

As you know, in an effort to formulate an approach to involve industry in the provision of synchrotron radiation facilities for x-ray lithography, a number of meetings were held first at Brookhaven National Laboratory, later at the University of Wisconsin and at various other locations to explore the several possibilities. These meetings were held jointly with members of the industrial community who needed and/or would produce sub-micron chips using x-ray lithography; the industrial community who would build and market the accelerator facilities and other critical subcomponents such as the steppers, the resists, the masks and the wafers; and the national laboratories who would provide technology transfer, design assistance, advanced design approaches, know-how and practical experience with systems built and operating. Also, the SEMATECH organization was formed to provide coordination among U.S. chip manufacturers and users on further development of a U.S. micro-chip industry.

In our view, four rather clear objectives came out of these meetings and discussions:

1) **Provision of Additional X-Ray Beamlines**

   Additional synchrotron light source beams should be made available as soon as possible to extend the experimental facilities required to demonstrate all facets of x-ray lithography.

2) **Provision of a Next Generation Light Source**

   Storage ring configurations that demonstrate more optimum approaches to the design of a commercial synchrotron light source should be designed and built.

3) **Pilot Manufacturing Plant Layout and Requirements**

   Complete synchrotron-based x-ray lithography plant designs that would include trade-off and cost-optimization studies between compact conventional and superconducting magnet synchrotron light sources should be accomplished through interactions among ultimate users, sub-micron chip manufacturers and subcomponent manufacturers. Complete systems studies, trade-offs and cost comparisons on conventional versus superconducting magnet electron synchrotron storage rings can be made on the basis of analyses, because no hard evidence yet exists that show the characteristics of a working superconducting magnet facility. These studies should be accompanied by a commercialization plan for synchrotron based x-ray lithography systems and a proposal for a pilot plant.

4) **R&D on Superconducting Magnets**

R&D on superconducting magnet synchrotron light sources should be initiated as soon as possible so that the database available to total facility designers is more realistic and relevant.

It is clear that Congress intended that the funds provided in Fy 88 be utilized by industrial firms insofar as possible and practicable and that industry play a major role in the commercialization process. Since these Fy 88 funds do not in and of themselves provide complete facilities, it is imperative that the Fy 89 funds appropriated by Congress significantly augment the funding provided in Fy 88, (which is already significantly lower than that required to merely get the x-ray lithography commercialization program under way) if this process is to proceed in an orderly manner.

SAIC, recognizing that it can and should play a major role in developing a commercialization plan for synchrotron-based x-ray lithography commercial facilities, has reviewed its capabilities for accomplishing the objectives stated above and has formed a team with General Atomics and Bechtel National to jointly develop, design, build and operate the facilities that are required to be in place over the next five years when pilot plants that will produce sub-micron chips in a production environment should be in place. In accomplishing these objectives, we intend to work with the users and potential manufacturers of sub-micron chips and with the suppliers of equipment required to transport the x-ray beams and manufacture the chips. We also plan to utilize fully the information developed at the national laboratories through their Technology Transfer and Work for Others programs. In addition, we look forward to the individual involvement of university and national laboratory experts throughout the fields of synchrotron storage ring design, construction and operation. We also plan to involve individuals and industries who are expert in the design and manufacture of the apparatus required to produce the sub-micron chips with the x-ray beams provided by the electron storage rings. We hope to expand our team to include a chip manufacturer and/or user. We will also integrate the fine work going on at Stanford and Cornell, ORNL, LBL, ANL and others as well as the programs at BNL and Wisconsin which were cornerstones of your plans for the initiation of this commercialization effort in Fy 88.

I would like now to briefly mention the companies involved in our consortium. SAIC is a diversified, high-technology company specializing in systems integration. SAIC's annual revenues exceed $700M and SAIC employs over 8,500 people. SAIC has the proper infrastructure for this effort starting with a particle accelerator division located in Princeton, New Jersey. SAIC has the experience to manage large systems integration projects as demonstrated by our successful completion of many such projects including one with a value greater than $250M. SAIC has the experience to manage particle accelerator projects and to design, fabricate and install them and associated beamline equipment. SAIC is the industrial contractor for and is involved in all phases of a highly relevant project for Loma Linda University Medical Center that includes design, fabrication, installation and commissioning of a proton synchrotron for cancer therapy. In this case, we are working with FNAL on the design of the accelerator.

SAIC's team member General Atomics (GA) is a diversified, high-technology company that has been very successful in technology transfer. GA has annual revenues of approximately $159M. GA also has a particle accelerator division, in fact, SAIC's and GA's two divisions are usually the lead competitors for particle accelerator projects. Teaming on this activity signifies the challenge presented by Congress and also our two corporations' views that long-term commercial success in x-ray lithography will require a U.S. team approach because the international competition is so formidable.

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SAIC's team member Bechtel is one of the largest international architect/engineering firms. Bechtel's annual revenues exceed $5.6 billion and Bechtel employs over 20,000 technical people plus construction personnel on its projects. SAIC selected Bechtel for this team because of their success in working with high-technology companies and universities on activities of this type and their commitment to x-ray lithography. Also, Bechtel is a member of SEMATECH.

With regard to the four objectives mentioned above, the SAIC Team has taken the following actions:

1) **Provision of Additional X-Ray Beamlines**

Submitted a proposal to Louisiana State University for the provision of a storage ring that would meet all of their requirements. The SAIC Team is committed to build this facility as an industrial enterprise with full responsibility for design, fabrication, installation and commissioning residing with the SAIC Team. We will be using design approaches developed for Aladdin at the SRC of the University of Wisconsin. In the circular sections, this facility comes close to a state-of-the-art model for a synchrotron based x-ray lithography system with commercial potential. This project, of course, cannot be completed without additional Fy 89 funding.

The SAIC Team, at its own expense, is also working with the University of Wisconsin in order to understand the x-ray lithography experimental program being run on Aladdin, particularly in view of the additional emphasis being placed in this through the Congressional initiative process. We plan to use this experience to assist LSU and others in the provision of beamlines at a later stage in the program.

2) Construction of a Synchrotron Light Source of Advanced Design at BNL

In Fy 88, one of the initial steps envisioned for the development of a commercial synchrotron light source was to build at BNL a light source specifically designed to meet the x-ray beam requirements for a commercial x-ray lithography facility. This device would be designed for this purpose only and not be a machine designed for research applications. It would be another step along the way towards the provision of a compact commercial light source and would significantly advance the state-of-the-art.

The SAIC Team has met with BNL and presented its capabilities for designing and building a synchrotron light source of advanced design. In these discussions, the SAIC Team has stressed its contention that the industrial team chosen by BNL as its industrial partner for the design and construction of a new light source facility at BNL should be given significant design, fabrication, management and commissioning responsibility as opposed to purely engineering assistance. We believe this is necessary to ensure effective technology transfer through full involvement in all aspects of project execution for maximum training and preparedness to manage the follow-on commercialization phase. We also encouraged BNL to chose a team such as ours with total systems capabilities including buildings, facilities, construction and provision of experimental area apparatus in addition to expertise in accelerator systems and established success in program management and high technology. We believe BNL will endorse our approach and recognized the broad capabilities of our team. We are now awaiting their RFP based on the completion of their conceptual design. This effort needs to be more fully funded in FY 89 if the commercialization in 5-years goal is to be achieved. Projects such as this cannot be properly executed without sufficient funding commitment to ensure continuity of effort.

3) Pilot Manufacturing Plant Layout and Requirements

The SAIC Team is fully prepared to develop a commercialization plan and the preconceptual design of a synchrotron radiation based x-ray lithography pilot plant on a cost-sharing basis, providing their involvement in the above programs is sufficient to warrant such an investment; the funding for the above programs is provided on a timely basis to ensure reasonable progress in the provision of a database from which a commercial plant preconceptual design can be developed and that the chip manufacturers and their customers are committed to the downstream use of this technology. We expect the facilities development experience of our partner, Bechtel National, to be a major asset in the development of a pilot plant layout. The SAIC Team also expects that these plans and designs will draw on the work done at the Federal laboratories and that laboratory personnel will be made available to assist in their formulation, to assess their applicability and to review their technical content. Conversely, based on sales of pilot plants and commercial systems, SAIC would be willing to reimburse the federal government and/or the laboratories and institutions which developed the design on a mutually agreeable royalty basis. Finally, we assume that SEMATECH will be the customer for developing and building a pilot plant and hope to establish a dialogue with them on this subject.

4) R & D and Designs for Superconducting Magnet Synchrotron Light Sources

The SAIC team is prepared to work with the federal laboratories and the universities to develop both preconceptual designs and R&D plans for superconducting magnet synchrotron light sources. Particularly through our partner, General Atomics, which has significant experience in the design and fabrication of superconducting magnet systems, we are also prepared to undertake superconducting magnet prototype R&D work.

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In conclusion, I would like to add that SAIC and its partners, General Atomic and Bechtel National, respectfully suggest that additional Fy 89 federal funding be applied to the projects that will start in Fy 88 and that the language in the Appropriation Bill include plans in the outyears for bringing these facilities and the others required to satisfactorily demonstrate a realistic U.S. commercial/industrial capability in x-ray lithography.

We would also suggest that the Department of Energy recognize the existence of these facilities and the need to nurture them as a part of their technology development programs and that the Administration set up an effective dialogue between those responsible for related programs in the Department of Energy and the Department of Defense to ensure that a well-coordinated, effective program is in place that fully conforms to the goals established by Congress and economically uses the special funding provided through the Congressional initiative process. We applaud Congress for their bold action on this program and assure you we at SAIC, GA and Bechtel will do our best to provide the industrialization effort you envisaged in a timely and effective manner.

The SAIC goal is not just to participate in the industrialization phase of synchrotron-based x-ray lithography but to establish a U.S. capability that ensures that the U.S. manufacturers are producing sub-micron macro chips soon enough to become leading producers and viable competitors in the world market.

Thank you for your attention and thank you for giving us this opportunity to speak to you about SAIC and its partners, General Atomics and Bechtel, and our support of and commitment to this important program you now have underway.

Mr. Stallings. Thank you, Dr. Dillon. Dr. Knotek?

STATEMENT OF DR. MICHAEL L. KNOTEK, CHAIRMAN, NATIONAL SYNCHROTRON LIGHT SOURCE, BROOKHAVEN NATIONAL LABORATORY, UPTON, LONG ISLAND, NY

Dr. Knotek. Thank you, Mr. Chairman. It is a pleasure to be here today. I am Michael Knotek, Chairman of the National Synchrotron Light Source, and I am here speaking for a very large group of people who have spent the last two years trying to formulate a plan whereby x-ray lithography can be brought into the technology stream by the 1990s.

We are aware that we face a very significant foreign competition in this area that could well take the lead in semiconductor technology away from the United States, which could have very dramatic economic and security ramifications for this country.

We are also faced with the problem that the vendor industry which would normally provide the technology to our semiconductor industry to carry out this work, is ailing and has been ailing because of foreign competition and is not capable of taking on this job on its own.

The only logical way to proceed is for the Government and industry to work together to share resources and expertise to try to get this program onto the ground quickly. This will require an unprecedented collaboration between the Government and industry in this area, and we think that for this project to be successful, it must focus tightly on three very significant goals.

The first of those is to produce a reliable set of x- ray lithography hardware in a pilot-plant environment as quickly as possible. Second, we must develop a vendor industry. We must revitalize our vendor industry and bring on the full range of technology, not just accelerator technology. And we must find a way to coordinate our activities to really tie all of our resources together to get this done in an efficient manner.

The National Synchrotron Light Source has been involved from the beginning in x-ray lithography research.

Could we get the lights lowered, please?

What I show here is a view of our vacuum-ultraviolet ring at the National Synchrotron Light Source. I want to make two points. One, this is the type of technology we are talking about transferring to industry. If anyone is under the impression from this that this is a simple device to build or operate, I would like to argue with them later about that topic. This is a very intensive technology and it pushes the National Laboratories and will certainly push our industry.

In the background in this photo you see the x-ray lithography effort that was established by IBM in the early 1980s at this facility to carry x-ray lithography research into the development phase. This effort especially made us aware that there was very rapid progress in x-ray lithography and that there was a push on to go from research to development.

I want to summarize some of the recent activity by IBM, who is the national and world leader in this area at this time.

The IBM effort is passed from their research groups at Yorktown Heights to their development groups at East Fishkill. They have committed to a pilot facility at East Fishkill to be centered around x-ray lithography. They have contracted for their own storage ring, and they have had to contract to an English firm, Oxford Engineering, to do that because there were no available U.S. vendors for that technology.

They have contracted to build a second facility at our storage ring, which will be just to the left of the one you see, and most importantly, they are very near to the completion of their first full wafer run of working half-micron design-rule chips using x-ray lithography and using the facility you see here.

They are very deeply concerned that they do not have the American infrastructure to support them in this technology. They have an investment now approaching $200 to $300 million in this area, and they are worried enough that they are willing to share their entire technology base with their competitors in this country in order to stave off the Japanese challenge. It is time for the U.S. Government to respond to that and help them.

A slight word about the Japanese effort. The Japanese effort, which is our major competition at this point, is now made up of seven different consortia or companies which are trying to field at this time ten synchrotron sources, and the Japanese project that they will have 80 to 90 synchrotrons on the ground between 1990 and 1995 for technological applications.

Two years ago our program office at the Department of Energy was very concerned about this and they urged us to action to try to get x-ray lithography out of the research environment you see here in to the factories.

May I have the second Vu-graph?

Starting two years ago, we held a series of workshops on x-ray lithography and had a very wide attendance by industries, universities and National Laboratories. This is the industrial participation at the workshops, and on the next Vu-graph is shown the participation by universities and National Labs.

These things were attended by essentially the entire spectrum of technologies and scientists that have expertise in this area, and they have gone together to form a plan, came out in the form of four workshop reports, and we have distributed thousands of these reports around the United States to all interested parties.

Now, out of this came several very clear recommendations, and the sense of these workshops I can summarize as follows. X-ray lithography is a viable technology, and synchrotron sources of x-rays for this technology will make it viable for the high-volume market. We are in a race with our foreign competition, but we still have a window of opportunity to respond.

X-ray lithography is a very broad technology, as you see in the next Vu-graph. There are a number of key elements, including masks, resists, aligner/stepper systems, processing, metrology and repair, and chip design. Each of these must be covered by any national plan if it is to be effective.

We need a coordinated effort utilizing resources of multiple industrial partners and Government and university laboratories. We will need to make full use of existing facilities at our synchrotron science centers around the country, and as you can see by the presence of our SAIC representative here, there is a large and capable group of industrial firms that are ready to move into this area.

The National Synchrotron Light Source has been involved from the beginning, and one of the reasons we are involved is that the National Synchrotron Light Source has the largest staff and resources dedicated to synchrotron radiation science anywhere in the world. We are ready to help in any way we can to make this happen.

The Department of Defense in 1987 gave us $750,000 to continue the work of our workshops and to proceed with help on designing viable synchrotron sources and supporting facilities.

On the next Vu-graph you can see a picture of the type of devices that we are talking about. The first one is a 1-GeV so-called conventional magnet storage ring. That is shown on the right. That device is something like half to two-thirds the size of the ring you saw in the first Vu-graph. That is the most conservative technology and has the greatest chance for success. If we built that, we are very sure that we could make it work and make it work rapidly and get it into a factory.

I would note that the Japanese effort is centered around just such a device. Their prime thrust is in that area, conventional magnet storage ring with a full energy injector.

Industry would like the smaller device shown to the left, which is a superconducting-based device, and we also have a research and development plan to try to bring that on somewhat later than the magnet device would come on. We have worked very extensively with industry over the last year to arrive at a formula where we can contract with industry and give them very substantial a role as a prime contractor and system integrator, and they would be involved in design, procurement, construction and commissioning of that device and then be able to take it on to commercialization.

Finally, I want to end up with some conclusions. We have been working very hard in this area, as have a great deal of other people, and we have found that there is a great enthusiasm to be involved by a broad segment of Government agencies, universities and industrial firms. The initiative taken by this Committee in 1988 was absolutely essential to get this moving, and we applaud that initiative and to see it moving on in 1989.

We would like to make the following suggestions. First, we feel a single comprehensive plan which extends across Government agency lines and between Government and industry must be established. This plan must be comprehensive, include full scope, schedules, costs and a management plan agreed to by all. A lead agency must be established to properly focus efforts, clarifying goals and responsibilities and to allocate all of the funding.

The funding profile for the duration of the project must be established and committed to so that long-lead and multi-year items can be properly scheduled and so that key people and institutions can make the necessary commitments to make this succeed.

I thank you for giving me the opportunity to speak with you today, and Brookhaven Labordory remains ready to do our part.

[The prepared statement of Dr. Knotek follows:]

Testimony
Before the House Subcommittee
on
Energy Research and Development

by
Michael L. Knotek
Chairman
National Synchrotron Light Source
Brookhaven National Laboratory
Upton, New York 11973

X-RAY LITHOGRAPHY

MARCH 29, 1988

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UV X
National Synchrotron Light Source

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.

Mr. Chairman and Members of the committee, my name is Michael Knotek and I am Chairman of the National Synchrotron Light Source at Brookhaven National Laboratory. I am pleased to have the opportunity to speak to you about the opportunities and challenges presented to us by the emerging technology of X-ray Lithography. The members of this committee are to be commended for their efforts to initiate a national program to help insure a competitive US position in this important area.

In the past two years cognizant scientists and engineers from industry,government laboratories, and universities have worked together to devise a plan to bring X-ray Lithography to the manufacturing level by the early 1990's. This must be carried out in the face of fierce competition from large, well funded and well coordinated efforts in Europe and Japan which could well take leadership in semiconductor technology away from the United States, and which could have very serious economic and security ramifications. The problem is compounded by the fact that the domestic Vendor industry which supports our semiconductor technology is ailing and has no members which can afford to unilaterally mount the effort necessary to bring X-Ray lithography technology to the marketplace. The recent formation of Sematech is an attempt by industry to pool resources to mount even nearer term technologies than X-Ray Lithography and illustrates the greater depth of the problem of competing in todays international environment.

A concerted application of government and industry resources seems to be the only viable avenue to timely development of this critical technology and indeed it is precisely such coordinated efforts which we face from our foreign competition. We have a roadmap for development of X-Ray Lithography. The implementation of a plan based on it, which requires an unprecedented collaboration of industrial laboratories, government laboratories, and academia, must focus strongly on key goals if we are to succeed. Those key goals include:

1) Produce reliable x-ray lithography hardware including a synchrotron x-ray source and other exposure and processing tools in a pilot plant environment as quickly as practicable.

2) Develop domestic vendors of all key tooling and hardware.

3) Coordinate activities to optimize use of industrial and government resources, including funding, expertise and facilities.

It is the plan to achieve these goals and its implementation which I want to discuss with you today.

AWARENESS OF POTENTIAL AND PROBLEMS

The National Synchrotron Light Source at its inception was predicated upon the heavy involvement by industrial scientists in research in which synchrotron radiation could be applied to advanced materials science problems with technological significance. Roughly 40% of the $60 million in experimental capitalization at the NSLS was established by industrial concerns with interests in semiconductor technology, petrochemicals, energy, biotechnology, and many more areas. The Department of Energy considers the NSLS an ideal technology transfer medium because of the many collaborations and other interactions between industry, national laboratories,and universities which form in the natural pursuit of synchrotron science. One of the key industrial efforts at the NSLS is IBM's program in X-Ray Lithography.

Recognizing that optical lithography would run into serious problems after a few more generations of reduction in feature size, IBM began its pursuit of X-Ray Lithography technology in the early 1970's and has been carrying out proof of principal experimentation at several synchrotron radiation facilities since then. In the early 1980's IBM established an X-ray

Lithography beamline on the NSLS VUV ring. IBM had established in early experimentation that soft x-rays could in fact be used to achieve feature sizes in the sub-sub micron range and that synchrotron radiation sources could give X-Ray Lithography the throughput of optical lithography and thus make it viable for the high volume DRAM market. Because of this effort and others being pursued at the NSLS and other Synchrotron facilities we were aware of early successful experiments in the field and of the rapid push to move from research to development. Most significantly, the IBM effort has been passed from the research groups at Yorktown Heights, NY to the development group at East Fishkill, NY, where they have committed to a pilot facility centered around X-Ray Lithography. IBM has contracted for their own storage ring (from Oxford Engineering, an English firm) to be sited at that pilot facility. They are adding a second beamline at the NSLS for the evaluation of industrial stepper/aligners, and they are near to completion of the first full wafer run of 0.5 micron design-rule chips using their facility at the NSLS. Their commitment now measures in the hundreds of millions of dollars and they are deeply concerned that there be a national domestic infrastructure to support X-Ray Lithography for the 1990's and beyond. IBM has signalled their intention to participate in any comprehensive program and to share elements of their technology base as part of a full domestic manufacturing capability.

While we were aware of the early successes of X-Ray Lithography, we were also aware of the degeneration of the semiconductor vendor industry in the US, in the face of foreign competition, and of the large, heavily funded and coordinated efforts in Germany and Japan to field X-Ray Lithography rapidly. For example, the Japanese initiative now includes seven different efforts leading to ten synchrotron sources, and they project 80-90 machines in place in Japan between 1995 and 2000. We saw US efforts outside of IBM gradually whither away and IBM being forced to go it alone in the face of this formidable challenge.

The DOE program office was voicing concern that while the US had the lead in X-Ray Lithography research, we were likely to lose the race to the marketplace because of the large government/industry consortia in Japan and Germany. More specifically, they were alarmed that although the US is second to none in synchrotron technology, the Japanese and Germans were fielding commercial sources via industry/government consortia, and we weren't. A race was on and we weren't even in it! They urged us to get something moving. Simultaneously we were hearing from a wider segment within government real alarm at the growing inroads into the onetime US dominance of advanced semiconductor technology by foreign firms, most notably Japanese firms, and of its potential national security impact.

ESTABLISHING A ROADMAP

In an effort to initiate the necessary technology transfer to industry, a series of five workshops have been held at Brookhaven, focussing on feasibility and parameters, technical options, cost and scheduling of a full technology, superconducting magnets, and modes of interaction with industry. The workshops were organized by scientists from Brookhaven, the University of Wisconsin, and industry, and were heavily attended by the semiconductor industry, vendor companies, national laboratories, government agencies, universities, and potential accelerator builders. Reports have been published on each of these workshops and circulation now numbers in the thousands. In addition to these workshops there have been hundreds of contacts with industry and additional workshops elsewhere, most importantly at the University of Wisconsin.

I can summarize the sense of these workshops as follows:

1) X-Ray Lithography is viable and synchrotron sources can give it the necessary throughput for high volume production.

2) While we are most definitely in a race with well organized and well funded foreign competition, there is a window of opportunity for action in which we can recover the lead.

3) X-Ray Lithography is a broad technology with many challenging engineering and materials problems. A viable X-Ray source is only one of several major pieces which must be brought simultaneously to the manufacturing level. Key pieces of technology include masks, resists, aligner/stepper systems, processing, metrology and repair, and chip design. Any effective plan must provide for each of these pieces.

4) A coordinated effort utilizing the expertise and resources of multiple industrial partners and government and university laboratories will be required to develop this technology in a timely way.

5) Full use must be made of existing experimental capabilities at synchrotron radiation research facilities throughout the US.

6) A large and capable group of industrial firms and consortia are prepared to move into this area of technology.

SYNCHROTRON SOURCE ACTIVITIES AT BNL

The National Synchrotron Light at Brookhaven National Laboratory has the most extensive staff and resources dedicated to synchrotron radiation research and development in the world. We are prepared to make that resource available to work with industry to quickly field a synchrotron source and transfer the necessary expertise to industry to insure domestic manufacturing capability.

In FY87 the Department of Defense supplied BNL with $750K to continue the studies begun in our workshops. As part of that effort we have prepared a conceptual study of a 1 GeV conventional magnet storage ring and full energy injector, and supporting facilities. We view the fast track acquisition of a 1 GeV storage ring and full energy injector as the most conservative option to assure a viable industrial source. Such a facility could be used to rapidly commission the storage ring and perform a full range of injection studies and other tests to arrive at the best commercial package. We note that the Japanese effort has as its primary thrust just such a combination.

We have also established a plan for an R&D program aimed at early development of a superconducting magnet compact storage ring, and have worked with potential superconducting magnet builders on designs and contractual relationships under which they would fabricate the magnets. We have developed a plan for rapid, low cost construction of a protoype compact ring lattice with conventional magnets which would employ some existing components and the existing injector at the NSLS to quickly perform crucial injection and beam dynamics studies.

In any case we feel it is critical that any national effort contain both conventional and superconducting options. Whatever is chosen as the first pilot source should have the other as backup. We would also argue against placing any untried source directly in a pilot plant environment.

Brookhaven National Laboratory has been working intensively and extensively with industry to prepare a number of very substantial consortia to accept requests for proposals for any effort that is fielded. BNL placed a Request for Qualifications to Participate in the development of commercial synchrotron sources and ancillary x-ray lithography equipment in Commerce Business Daily, and received 20 responses. We have worked with industry to arrive at a formula whereby Brookhaven Laboratory would work with an industrial partner, to be selected by competitive bid, to build a preproduction prototype of a compact synchrotron, to be placed at the NSLS. The industrial partner would have responsibilities in design, procurement, fabrication, commissioning and system integration. The staff of the NSLS and other synchrotron facilities in the US would subsequently work with them to perform the necessary commissioning, tests and experiments to then install a machine, possibly the same machine, of industrial reliability and performance at a pilot plant site.

CONCLUSIONS

Mr. Chairman, this initiative presents a significant challenge to us all but promises even greater benefit. I have absolutely no doubt that we can succeed. The diversity and breadth of the institutions and technologies involved requires decisive management action. We suggest the following:

1) A single, comprehensive plan which extends across government agency lines and between government and industry must be established. This plan must include full scope, schedules, costs and management plan.

2) A lead agency must be established to properly focus efforts by clarifying goals and responsibilities, and to allocate all funding.

3) A funding profile for the duration of the project must be established so that long-lead and multiyear items can be properly scheduled, and so that key people and institutions can make the necessary commitments.

Brookhaven remains prepared to do our part in this initiative.

I thank you for the opportunity to speak with you today.

BIOGRAPHY

Michael L. Knotek is Chairman of the National Synchrotron Light Source at Brookhaven National Laboratory. Dr. Knotek received his B.S. in Physics at Iowa State University in 1966 and his PhD in Physics at the University of California at Riverside in 1972. He was at Sandia National Laboratory in Albuquerque, where he was head of the Surface Physics Division, from 1972 to 1985. In 1985 he moved to Brookhaven National Laboratory as Chairman of the Light Source. Dr. Knotek has been active in Synchrotron Radiation research since 1978. In 1984 he co-chaired, with Dr. Peter Eisenberger the Planning Study for Advanced National Synchrotron Radiation Facilities. His research interests lie in Surface Physics and Chemistry, most recently in radiation induced dissociation and desorption effects.

Mr. STALLINGS. Thank you, Dr. Knotek. Dr. Huber?

STATEMENT OF DR. DAVID L. HUBER, DIRECTOR, SNYCHROTRON RADIATION CENTER, UNIVERSITY OF WISCONSIN-MADISON, STROUGHTON, WI

Dr. HUBER. Mr. Chairman, I take this opportunity to respond to your request for comments on the x-ray lithography program at the University of Wisconsin and our cooperative activities with industries and National Labs in the national program in x-ray lithography.

X-ray lithography at the University of Wisconsin has really two components. There is the Synchrotron Radiation Center, of which I am the director, and my job is to provide the x-rays for the people that do the lithography. We have a total of 36 ports on the ring. We have set aside five ports for x-ray lithography, and if the need arises we can set aside still more. We are at present the only storage ring in the country that has expansion space for x-ray lithography.

The campus activities in x-ray lithography are focused in the Center for x-ray lithography. This is a multi-professor interdisciplinary program involving faculty from electrical engineering and material science chemistry. They are funded, as we are, by the National Science Foundation, and in addition, they receive considerable funding from private industry.

There are experts working in the areas of mask development, photo resist and x-ray process modeling. Right now we train an estimated five to ten students a year, graduate five to ten Ph.D.'s a year in the broad area of x-ray lithography. If we are able to secure the funding that we are attempting to get this year, that number could double or perhaps even triple in the years to come.

As part of my written documentation in support of my testimony, I enclose a technical description of the x-ray lithography program and also something we will come to later on, a report of a workshop that we held last summer, the last of a series of workshops—the first three were at Brookhaven—where we brought together industry and universities and National Laboratory personnel.

In addition to the academic program in x-ray lithography, we are also now working with Honeywell and Perkin-Elmer in developing a response to the Department of Defense initiative in lithography. This would be an industrial-based activity carried out at the storage ring with the goal of at first testing x-ray lithography against optical lithography at the half-micron level, and later on extending x-ray lithography to the quarter-micron level, which is in the Sematech goals for 1995.

On the academic side, we are preparing a proposal that is to be submitted to Sematech Corporation. They have made available a total of $5 million to be awarded in approximately $1 million packages to five of the 13 finalists among the states which competed for the major Sematech headquarters; in this proposal, we would work together with faculty from Vanderbilt and Stanford University, people from Oak Ridge National Laboratory and a number of photo resist chemical companies to carry out an academic-based x-ray lithography program. In addition to the lithography, we would also undertake studies in x-ray assisted processing.

We hear a lot about lithography these days, but we think that x-ray assisted processing—that is, using the x-rays to carry out commercially valuable chemical reactions on the surfaces of semi-conductor materials—also holds great potential, and we propose to carry out a research program in that area.

We are also, as Dr. Dillon mentioned, working with SAIC and Bechtel National and General Atomics in preparing plans for the LSU storage ring. We are very proud of this work because it represents, we think, a significant technology transfer. Their plans are based on the Aladdin storage ring which was developed with NSF money over the years, and we would, in effect, transfer that technology to industry, making it available and really giving it wide applicability in the country.

I had mentioned that Wisconsin is the only storage ring which has expansion space for x-ray lithography in operation at the moment. In order to take full advantage of these capabilities, we believe it is necessary to build an addition to the Aladdin building, or what we call an industrial support center. The State of Wisconsin in recent legislative action has approved bonding for the construction of the support center, and we anticipate that construction would get under way later this year.

This support center building would house facilities which would be used by companies coming to do x-ray lithography work at the storage ring. The idea is the State would construct the shell, and Federal money would be needed to outfit the building in terms of the various measuring devices, analytical and diagnostic tools that will be needed to study the x-ray lithography process.

In addition, we will be approaching the Department of Defense for funding for an x-ray stepper. We believe this is a key component of an x-ray lithography program that has the goal of taking x-ray lithography from the laboratory into the manufacturing line, and we hope to have that stepper up and running within the next year.

Finally, I conclude, if I may, by just reading the conclusions of the workshop report. This was a workshop which was attended by nearly 50 people from industry, National Laboratories and universities, and it was held in Madison last July. The report was drafted early in the fall, but I think even though it is some six months later, I think the conclusions of the workshop are still very relevant, and let me just read them to you.

For the U.S. to remain competitive in technology to manufacture next generation integrated circuits, it is necessary to begin immediately a national x-ray lithography program to match the large-scale efforts of our foreign competitors. The alternative is to acquire foreign manufacturing technology that may force the United States to become ever more dependent on overseas suppliers of commodity and supercomputer chips.

A coordinated Government, industry and university program should first establish the commercial viability of x-ray lithography and then initiate a pilot production program that utilizes synchrotron x-ray radiation from a dedicated storage ring.

Since the United States is already late in starting this critical manufacturing technology, it is essential the program be initiated in 1988 if the U.S. semiconductor industry is to be a competitive supplier of high-volume IC's in the world marketplace.

That is the conclusion of the recommendations of the workshop report. Let me add that not only should it be initiated in 1988, in which, of course, your Committee has played a role, it should also be continued in 1989 and for several years to come.

Thank you.

[The prepared statement of Dr. Huber follows:]

Synchrotron Radiation Center
University of Wisconsin-Madison
3731 Schneider Drive
Stoughton, WI 53589-3097 (608) 873-6651

Memorandum

TO: U. S. House of Representatives
Committee on Science, Space, and Technology
Subcommittee on Energy Research and Development

FROM: David L. Huber, Director, Synchrotron Radiation Center,
University of Wisconsin-Madison

RE: Written Documentation in Support of Testimony by D. L. Huber,
March 29, 1988

DATE: March 24, 1988

In my testimony, I would like to bring to your attention a number of activities relating to x-ray lithography (XRL) in which the Synchrotron Radiation Center and the Center for X-Ray Lithography of the University of Wisconsin-Madison have been directly involved. Taken together, these activities show a commitment on the part of the University to work together with industry and national laboratories on a national program in x-ray lithography.

Attached to this memorandum is a description of the Wisconsin XRL program that is contained in the report of the workshop "X-Ray Lithography: The Next Three Years" which was held in Madison, July 21-22, 1987. The workshop, which was funded by the DoD and the NSF, was attended by forty six people from industry, universities, and national laboratories. I have also attached the Executive Summary of the report, which provides an overview of the opinions of the attendees on the status of XRL and the format for a national program.

University of Wisconsin staff are working with a number of organizations in the area of XRL. Together with Perkin-Elmer and Minneapolis-Honeywell, we are preparing a white paper for the Department of Defense where we will outline a plan to evaluate the performance of XRL in comparison with optical technology at the 0.5 micron level and extend the limits of XRL to the 0.25 micron level required by the SEMATECH timetable for 1995. The white paper will be followed by a detailed proposal for a research and development program to achieve that goal.

The University is also preparing a proposal for a SEMATECH Center of Excellence. We would collaborate with scientists from Oak Ridge National Laboratory, Vanderbilt University, Stanford University and a number of IC manufacturers, semiconductor equipment manufacturers, and photoresist suppliers in the areas of XRL and x-ray assisted processing.

We are also working with SAIC, General Atomic, and Bechtel National on the design of storage-ring based XRL facilities which would be utilized in industrial applications of lithography. In particular, we have assisted SAIC in preparing their plan for the LSU storage ring, which is modeled on the Aladdin storage ring at the Synchrotron Radiation Center.

Aladdin is the only storage ring in the country which has space available for research and development in XRL. In order to take full advantage of this facility, it is necessary to build an industrial support center adjacent to the Aladdin building. The State of Wisconsin has agreed to provide the building, once arrangements have been made to recover construction costs. In addition to the support center, it is essential to acquire an x-ray stepper which would be installed at the ring. Federal funding will be needed for outfitting the support center and for the stepper.

Finally, I would like to emphasize the need for a multi-year national program in XRL to match the large-scale efforts of our foreign competitors. Congress has taken an important first step in allocating $25M to XRL in the '88 budget. To quote from the conclusion of the workshop report, it is essential that this program be continued "if the U.S. Semiconductor Industry is to be a competitive supplier of high volume IC's in the world marketplace".

DLH:lmb

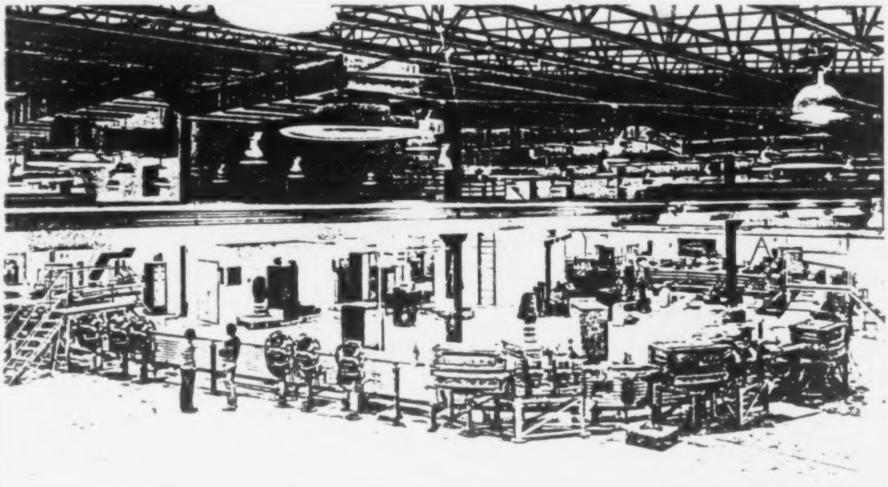


Figure C-6. View of the Aladdin Storage Ring

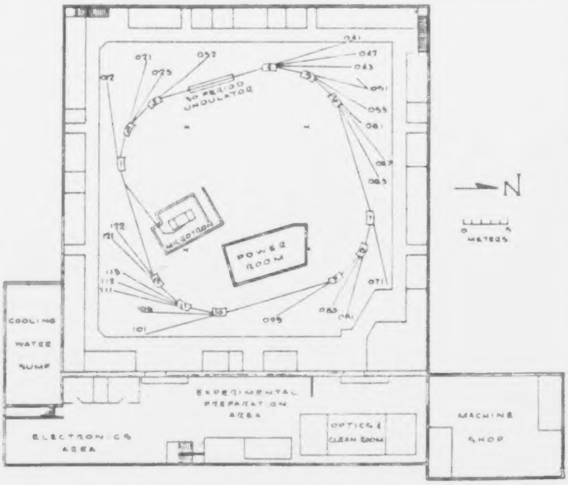
C.2 X-Ray Lithography at the University of Wisconsin

Wisconsin Synchrotron Radiation Center

The Wisconsin Synchrotron Radiation Center (SRC) operates a 1-GeV electron storage ring as a dedicated source of synchrotron radiation. This storage ring, called "Aladdin," has been constructed with 36 beam ports and four long straight sections to accommodate insertion devices such as undulators and wigglers. A photograph and plan view of the storage ring are shown in Figures C-6 and C-7.

It is important to note that Aladdin's spectral output, shown in Figure C-8, is ideally suited for X-ray lithography and can be tuned to emulate the characteristics of compact storage rings being developed as commercial X-ray sources.

The first SRC facility was built around "Tantalus," a small 240-MeV storage ring, construction of which began in 1965. Over the past 18 years, research programs at the SRC have been extremely successful. SRC first demonstrated the superiority of electron storage rings as a source of synchrotron radiation and undertook the first serious effort to use a wiggler to extend the emission spectrum of a synchrotron source.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121
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50 PERIOD UNDULATOR
MICROTRON
POWER ROOM
N
0 5
METERS
COOLING WATER SUMP
EXPERIMENTAL PREPARATION AREA
ELECTRONICS AREA
OPTICS & CLEAN ROOM
MACHINE SHOP

Figure C-7 Plan View of SRC Facility and 1 GeV Storage Ring

An important breakthrough for X-ray lithography was the design and application of a 100-MeV microtron as an inexpensive injector for storage rings by the University of Wisconsin. This has allowed the SRC on a restricted budget to operate Aladdin with a 95% up-time.

The SRC is a national facility open to qualified investigators at no cost and is operated by the University of Wisconsin-Madison with funding from the National Science Foundation. Over 900 publications based on work at the Center have appeared in the scientific literature since the time the the first storage ring, Tantalus, was placed in operation in 1968.

SRC shares its location and many facilities in Stoughton, WI with the University's Physical Sciences Laboratory. Two of Aladdin's ports are operated by the Wisconsin Center for X-ray Lithography in association with the Wisconsin Center for Applied Microelectronics.

In 1969, a Users Advisory Committee was established. This committee was given the broad objective of advising the Director of the Synchrotron Radiation Center on special needs and wishes of the User's Group with regard to the operation and development of the Center. SRC's success with this committee is the basis for our suggestion that a Technical Advisory Board be made part of the organization for a National Synchrotron X-ray Lithography Program. Research teams at the SRC have full access, on a cost recovery basis, to all University of Wisconsin-Madison facilities that include scientific, engineering, computing, and library facilities at the University and the extensive shop facilities at the Physical Sciences Laboratory (PSL), adjacent to the SRC.

To support X-ray lithography R&D, the University proposes to construct a new building adjacent to the SRC facility for the XRL Support Center.

Wisconsin Center for X-Ray Lithography

This university center operates two beam lines at the Synchrotron Radiation Center. Research performed by university and industry scientists includes: X-ray mask fabrication, mask distortion and damage assessment, oxide radiation damage assessment, X-ray resist characterization, X-ray optics and beam line design, and XRL process modeling.

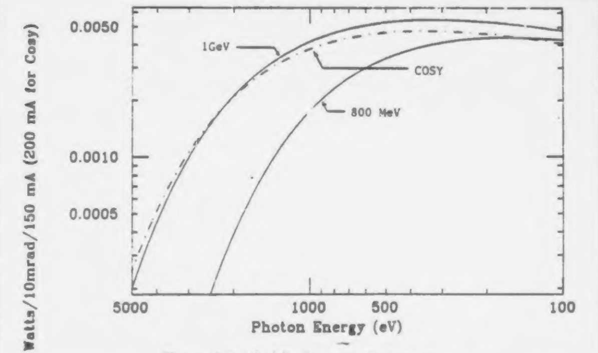


Figure C-8. Aladdin Emission Spectrum

The University will continue to operate these beam lines to provide research data to IC manufacturers that receive development contracts under the National Synchrotron Lithography Program. In addition, the center will work with X-ray lithography equipment manufacturers, X-ray mask suppliers, and resist developers to help them in their evaluation and refinement of these critical components.

Beam Line Description

Synchrotron radiation emerges from ports in the storage ring in the form of a flat "fan" that exhibits uniform intensity in the horizontal plane. In the vertical plane, the beam has a narrow, approximately Gaussian intensity profile, as illustrated schematically in Figure C-9. When a wafer is exposed, it is necessary to distribute this radiation uniformly over the mask.

The simplest method to expose a wafer is to raster scan the X-ray mask mechanically: the mask and wafer are clamped together and translated across the stationary beam. A more sophisticated method involves "steering" or wobbling the electron beam inside the synchrotron to physically move the position of the radiation source. However, this method is difficult to accomplish simultaneously for more than one port on a multi-port storage ring.

A third, more practical technique, uses a grazing-incidence scan mirror to sweep the X-ray beam across the wafer. The Center for X-Ray Lithography has designed and constructed beam lines and exposure stations that utilize both the mechanical and optical scanning techniques.

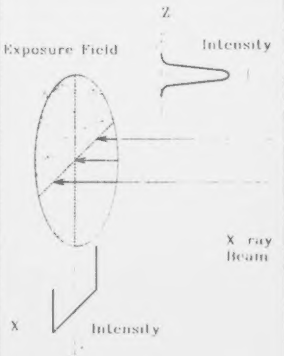


Figure C-9. X-Ray Radiation Profile

TABLE C-3.
WISCONSIN BEAM LINES

	ES-0	ES-1	ES-2
Scanning	Mechanical	Mirror	Mirror
Length	5m	8m	8m
Window	Be 10μ	Be 10μ	Be 10μ
Bandpass	Adjustable	Tunable	Fixed
Exposable area	1"x4"	6"x6"	6"x6"
Subfield	25x10 mm²	25x50 mm²	25x50 mm²
Wafer Mount	Mechanical	Electro-Static	Electro-Static
800 MeV Power (mW/125mA) Measured	406 (337)	97	287
Subfield exp. time(s)	10	120	40
1 GeV Power (mW/125mA)	2150	315	1300
Subfield exp. time	2	40	10

Table C-3 summarizes the characteristics of three exposure stations designed by the University that have been designated ES-0, ES-1, and ES-2. Exposure station, ES-0, was designed and constructed as a simple and expedient system to support early experiments. ES-2, a production version of ES-1, has been fully designed but is waiting to be constructed.

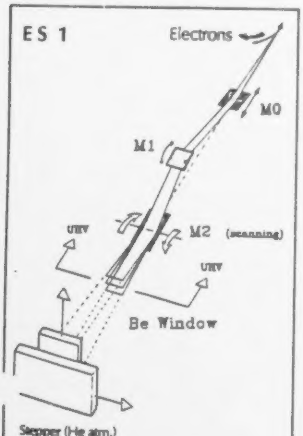
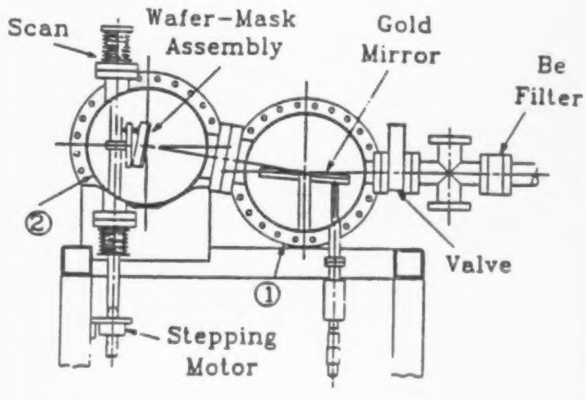


Figure C-11. Illustration of Optical Scanning System Used for ES-1



Wafers	4" diameter
Masks	4 x 4
Exposed Area	1" x 4"
Mechanical Scan	(computer control)
Vacuum	10^{-5} Torr
Gold Mirror	Off → 86°
Be Window	1 μm
Filters	Al, Cu, etc.
Adjustable gap	
Power (89°)	2.7 mW/mA/7mrad

Figure C-10. Cross-Sectional View and Specifications for Earliest X-Ray Lithography Exposure Station, ES-0

Figure C-10 shows a cross-sectional view of ES-0, and Figure C-11, illustrates the X-ray optical scanning system employed in ES-1. Both ES-0 and ES-1 exposure stations are totally flexible for XRL experiments. The spectral bandpass of ES-0 is adjustable, but it remains fixed during any one experiment, whereas ES-1 is capable of continuous, real-time tuning of the bandpass. If desired, the mirror M1 in ES-1 can be replaced by a grating to provide nearly monochromatic illumination.

X-Ray Mask Research and Development Support

ersonnel at the Center for X-Ray Lithography recently completed a series of joint experiments with Hewlett-Packard to evaluate the distortion of boron nitride masks. The Center has also provided facilities and assistance to the AT&T Bell Laboratories for experiments to appraise possible radiation damage to X-ray mask membranes. Figure C-12, is a SEM microgram of 0.2-micron lines exposed in PMMA resist using a Hewlett-Packard mask in the ES-0 beam line. The sharpness of the edgewalls can be seen in Detail A.

In addition to operating the beam lines and exposure stations, the Center for X-Ray Lithography has started to acquire a limited resist processing and analysis capability at the Aladdin site. Two laminar-flow benches have been installed, one of which is equipped with a spinner for applying resists. Plans exist to expand this processing capability and to acquire an optical and electron microscope. Presently, SEM and surface analysis are performed at the University Materials Science Center.

A Moire interferometer for mask distortion studies was built and put into operation in 1986, and a scanning interferometer for the measurement of resist dissolution rates is now being designed.

The five X-ray lithography ports on Aladdin are located at two adjacent bending magnets to allow them to be enclosed in a single, partitioned cleanroom. A plan view of the ports are available for XRL R&D are shown in Figure C-13 and C-14. Two additional ports can be assigned to XRL should the need arise.

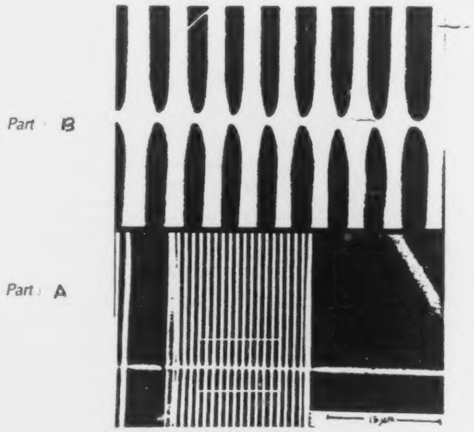


Figure C-12. 1-micron pitch grating with 0.2-micron transverse line exposed at ES-0. The mask used was a Hewlett Packard B_4NH:W process and the resist is 2-micron MMA. Notice high aspect ratio from the left most grating line (in part A) that has fallen over. Part (B) is the enlarged region boxed in Part (A).

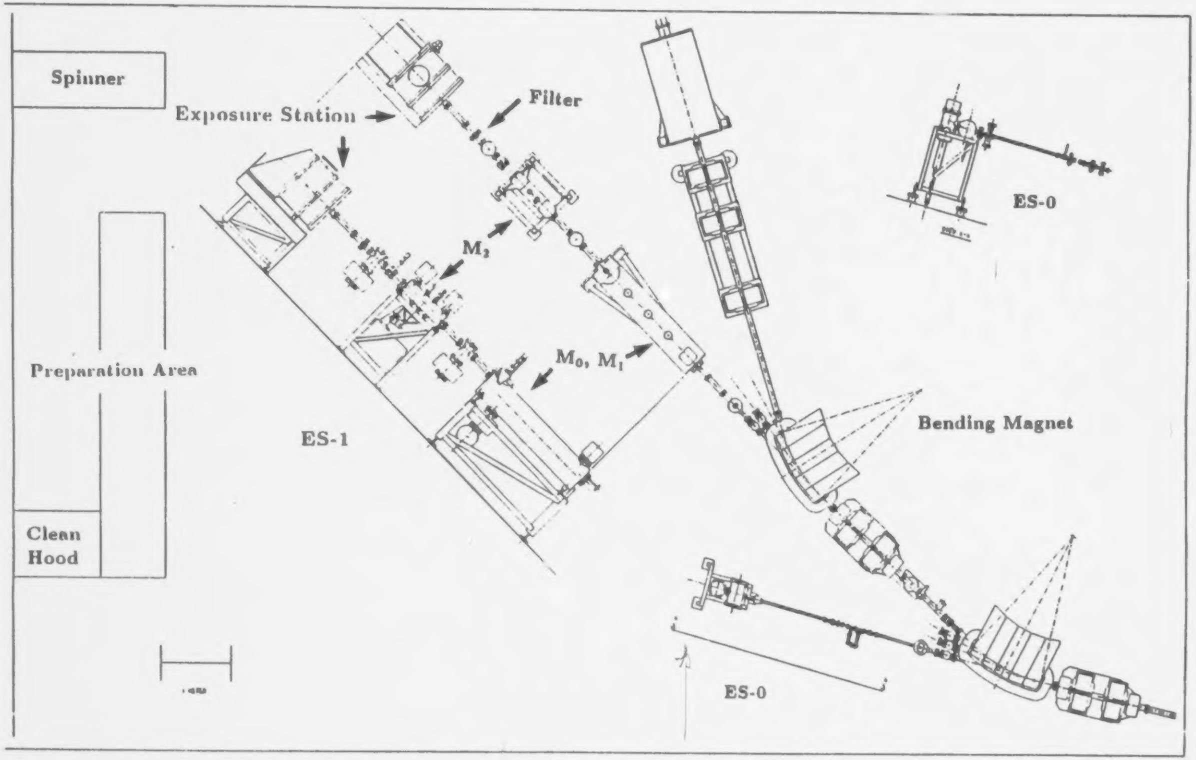

Spinner
Exposure Station
Filter
Preparation Area
M₂
M₀, M₁
ES-1
Clean Hood
Bending Magnet
ES-0
ES-0

Figure C-13. Typical Layout of XRL Beam Lines

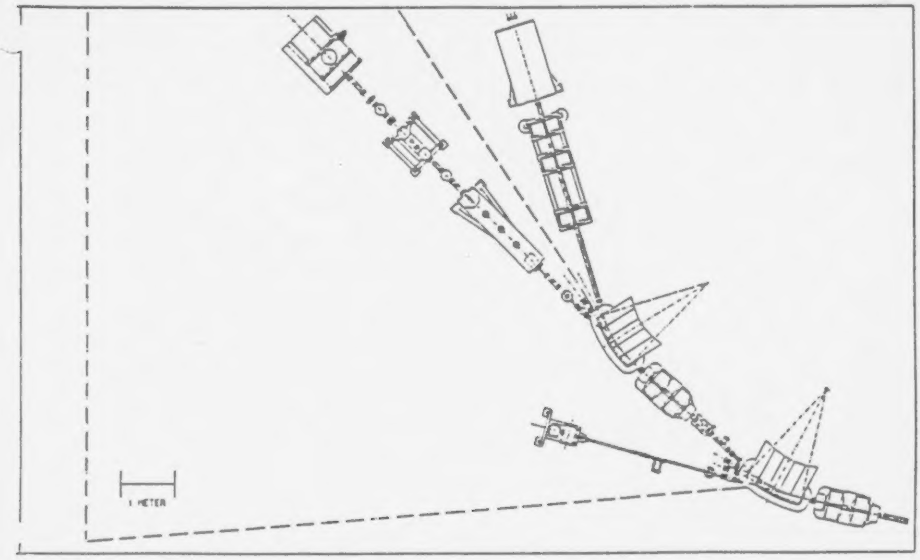


Figure C-14. Plan view of Aladdin showing current XRL Beam Lines. Broken lines indicate area set aside for XRL R&D.

Report of the Workshop

X-Ray Lithography: The Next Three Years

Held in
Madison, Wisconsin
July 21-22, 1987

Under Sponsorship of
The University of Wisconsin-Madison
Center for X-Ray Lithography and
Synchrotron Radiation Center
with Support from
The National Science Foundation and
The U.S. Department of Defense

Executive Summary

X-Ray Lithography Workshop Participants And Purpose

On July 21-22, 1987, forty-six members of government, industry, and university organizations attended a workshop entitled, "X-Ray Lithography: The Next Three Years," at the University of Wisconsin-Madison. Included in the attendance were representatives of most of the major IC manufacturers, the IC equipment and resist suppliers, and representatives from several national laboratories and universities. The purpose of the workshop was to provide a national forum to review the status of X-Ray Lithography (XRL) research and to reach a consensus on the format for a national program.

The Future Goals Of The Semiconductor Industry

A strong case was made that U.S. manufacturers must be prepared to implement 0.5-micron IC pilot lines by 1990 and have manufacturing-worthy 0.25-micron technologies under development by the mid-1990's, in order to provide a capability to manufacture 64-megabit memory chips with 0.25-micron minimum features.

The Case For X-ray Lithography And Foreign Competition

Worldwide research indicates that storage rings may be among the critical tools needed by the U.S. electronics industry to remain competitive in the decade ahead. Storage rings provide high levels of stable, collimated X-ray flux to pattern commodity IC's and super memory chips with submicron features. Germany and Japan currently lead the U.S. in adapting these synchrotron radiation sources for commercial XRL. Work abroad is being performed by consortia of IC and equipment manufacturers, universities, and national laboratories, with government funding.

In Europe, a large program involving essentially all major German electronics firms, as well as several universities and national laboratories, has been mounted. This program has received over $50 million in government funds since 1978 and is being coordinated by the Fraunhofer Institute. An additional $35 million in government and private funding has been used to construct an XRL R&D facility adjacent to the BESSY synchrotron.

In England, Oxford Instruments and the English national synchrotron laboratory at Daresbury are manufacturing a compact storage ring for IBM that they hope to sell commercially. A second multi-national XRL consortium in Europe, including Thompson (France), the Imperial College (U.K.), and SGS (Italy), uses the storage ring at Frascati.

The Japanese have launched a major, well-coordinated program that involves government, industry, and university cooperation. The major focus of this activity is a 13-company consortium, called "Sortec." More than fifteen new storage rings for x-ray lithography and x-ray assisted processing are known to be under development in Japan.

The National Program

Funding has been recommended to establish the technical and commercial viability of XRL within the next three years. If this first phase of the program is successful, an option will exist for government and industry to undertake a pilot production program and a superchip design activity. A summary of this proposed national initiative is described Section IV.

The first storage ring in the U.S. dedicated to X-ray lithography should utilize conventional magnets. The design of the storage ring should emphasize reliability, maintainability and ease of operation. Because this ring may be a prototype for commercial X-ray sources, manufacturability and low cost are also important considerations. Low energy injection schemes should be explored for the next generation of machines. The group also recommended that a detailed study be made of compact storage rings that use superconducting magnets.

A National Research Facility

A national XRL program would serve the important function of providing IC manufacturers with mask-to-wafer alignment systems, resist processing facilities, and mask metrology equipment at the Wisconsin Synchrotron Radiation Center (SRC). It was proposed that an XRL Support Center be established in a new building adjacent to the SRC Aladdin facility to provide specialized equipment and services to the research teams and R&D contractors working in Madison.

The Wisconsin SRC operates the Aladdin storage ring as a dedicated source of sychrotron radiation. Five of Aladdin's 36 ports are dedicated to XRL R&D, but two additional ports can be made available if the need arises. When operated at 1 GeV, Aladdin's spectral output is ideally suited for X-ray lithography.

A support Center should be equipped at the storage ring site to fabricate standard test masks to assist the IC manufacturers in XRL process development and resist evaluation; these masks would not necessarily need to be patterned at the VLSI level of complexity. The objective of the work to be performed at the Support Center would be to establish the technical and commercial viability of XRL, and no attempt would be made to manufacture commercial masks with a 0.25-micron patterning capability.

The Technical Challenges

Existing tools appear to be adequate to demonstrate the technical and commercial viability of XRL and to establish a limited 0.5-micron production capability by 1990. However, to achieve a 0.25

micron manufacturing capability by the mid-1990's, next-generation E-beam, inspection, and mask repair tools must be developed.

X-ray mask availability was identified as the largest single obstacle to the development and ultimate application of X-ray lithography to high-volume IC production. The problem is not the availability of X-ray masks for R&D, but the lack of equipment and technology required to fabricate stable, low-defect masks that meet the overlay requirements of next-generation VLSI chips. Commercial X-ray mask fabrication will require work in four broad technical areas: materials technology, E-beam patterning, mask inspection, and mask repair.

Because the cost and complexity of next-generation IC manufacturing technology has increased significantly, few U.S. companies have the resources to pursue a high-risk manufacturing technology program that may have a five- to seven-year lead time. IBM is the only electronics manuacturer with a major public commitment to XRL.

Work must begin immediately at existing synchrotron centers if the U.S is to demonstrate the commercial viability of X-ray lithography in manufacturing integrated circuits within the next three years.

Conclusions

For the U.S. to remain competitive in the technology to manufacture next-generation integrated circuits, it is necessary to begin immediately a **national** X-ray lithography program to match the large-scale efforts of our foreign competitors. The alternative is to acquire foreign manufacturing technology that may force the U.S. to become ever more dependent upon overseas suppliers of commodity and supercomputer chips.

A coordinated government, industry, and university program should first establish the commercial viability of XRL and then initiate a pilot production program that utilizes synchrotron X-ray radiation from a dedicated storage ring. Since the U.S. is already late in starting this critical manufacturing technology program, **it is essential the program be initiated in 1988 if the U.S. Semiconductor Industry is to be a competitive supplier of high-volume IC's in the world marketplace.**

PANEL 1 DISCUSSION

Mr. **Stallings**. Thank you, Dr. Huber. Mr. Morrison, I'm going to have you proceed with the questions.

Mr. **Morrison**. Thank you, Mr. Chairman. I think this technology is obviously one that is an example of what tears this Subcommittee and that is you are right at the point of blending into private enterprise and it looks like private enterprise isn't really ready.

I'd like to just maybe ask a general question that would relate to this interface with industry. I notice that IBM, according to several of your testimonies, is ordering from England the mechanics of proceeding to a certain extent on their own, and of course, you are part of groups that interface with industry.

I guess I'm just wondering, is this working well, are we on the right track? I think what you're telling us in your testimony is that as long as you have sufficient funding for the governmental role that, in fact, we are proceeding down the right path with x-ray lithography. I'm interested in your reactions, any of you.

Dr. **Dillon**. I'd like to just say something from an industry perspective. The reaction we've had working with both Brookhaven and with the University of Wisconsin, is a very, very pleasant surprise. And, I don't want to imply that I was expecting a lot of problems, but all of these activities, at this point really, have been largely financed by the companies involved because, although we're envisioning procurements from LSU and hopefully sometime from Brookhaven, at this stage it's really involving completely private investment.

But, the University of Wisconsin was a full-fledged, integrated team member. We got the advantage of their best people helping us figure out what the lessons learned were from Aladdin, and I think that picture shows you that a synchrotron light source sounds like a simple thing.

It's very simple to lay out the components and say you're going to have an injector in a ring, but when you actually go and try to put it into operation and make it work and have it day after day deliver reliable beam current, it's a much more difficult proposition.

So, having that kind of a working relationship with the labs, with the University, makes a tremendous difference to an industrial entity because that definitely helps us reduce the risk involved in getting into a commercial venture in this area.

Dr. **Huber**. Let me just add to that. The University of Wisconsin has a long tradition of working with industry in all kinds of activities.

Lately, the state government is beginning to recognize the potential of the University for contributing to economic development in the State, and I think that was one of the ideas behind their going ahead and making available money to construct the building. That is, they're anxious to foster high technology industries in the state, and I think that is true also in other states around the country.

Dr. **Knotek**. I want to say something about the interaction with IBM. We've had extensive interactions at IBM since they have a facility at our light source, so they talk to me almost weekly about what they're doing and what they need to make their program succeed.

They have been our key source of information and guidance in this project from the beginning, and one of the reasons they were forced to go overseas for accelerator technology, and I might add they are going overseas for other technology as well, steppers at this point, is that they were saying while we were making much greater progress, and the progress they saw out of this Committee was something they just could not believe had happened so rapidly, but they said they could not afford to wait. They must go their own to make this work.

They're going to be a full partner in anything we do, but we have to move faster. We must get things solidified, we must get all the government efforts pointed in the same direction, and somebody must guide it from the top and make sure the right things happen, and on time.

Mr. MORRISON. So, they're moving out on their own really doesn't undercut what you're doing?

Dr. KNOTEK. No, it's very much complementary. As a matter of fact, all the workshops and all the conceptual studies we've done, their engineers have worked with us on the details of all of this.

They very much count on this effort to be something that will support them. They know they are in a risky business and that contracting to a firm to build a synchrotron, which never built a synchrotron before, is very risky, and they were counting on this effort to back them up.

Mr. MORRISON. I get the impression that this program is an excellent example of the interface that I think this Subcommittee would like to achieve in a number of energy research areas, so I compliment you and hope we can continue the funding so you can get on with this absolutely vital technology.

Thank you. Thank you, Madame Chairman.

Mrs. LLOYD [presiding]. Thank you very much, Mr. Morrison. Dr. Dillon, it's good to see you today. It's good to see all of our witnesses here.

Tom, do you expect that the SAIC and the Consortium will be receiving funds from the Department of Defense this year or next year? What do you really anticipate as the funding from this source in this year's budget, as well?

Dr. DILLON. Well, for this year for the two areas where we would be looking for funding would be through Louisiana State University in the synchrotron light source facility that they'll be procuring, and we'll be, of course, competing for that.

The other area where we would hope to be able to compete for funding would be through the Brookhaven program, which is looking ahead at what an x-ray lithography light source would be like, some advanced design concepts.

Mrs. LLOYD. But that's DOE money.

Dr. DILLON. Yes.

Mrs. LLOYD. That was my understanding what the DOD might be putting in, self-commitment. DOE civilian programs versus the Department of Defense energy programs.

Dr. DILLON. Well, I think the Department of Defense activities are mostly at the University of Wisconsin.

Mrs. **Lloyd.** Right.

Mr. **Knotek.** I can say another thing. The Department of Defense, in the area of a superconducting synchrotron source, has recently agreed to fund us on the advanced experiments on that source, which we should be getting immediately, and we will be back in touch with all the industrial consortia who have gotten themselves ready to react to this to get their participation, starting this year.

Mrs. **Lloyd.** Okay. Tom, what sort of commitment is the private sector going to make with you in terms of work at, for instance, University of Wisconsin and the Aladdin program. Can you sort of review the commitment that you'll be making on the private sector?

Mr. **Dillon.** Right now, what we are doing, of course, is everything is being done in private funding. We haven't had any Federal funding for what we're doing and that gets involved in pulling together really a pretty detailed design for the facility of LSU, based on the Aladdin experience, and the Aladdin design.

That activity has been privately funded and we're continuing, under private funding of the three companies involved in our team, to look at other aspects of what is going on in Aladdin to make sure that we're in a position as an industrial team to be as responsive as possible to the national program as it begins to unfold.

So, right now, all of the activity of our team, and it's been quite significant, has been completely privately funded. We're certainly hoping that we will begin to see some Federally-funded activities starting to come out that we'll be able to compete for and that is something that we were anticipating.

There was supposed to be proposals submitted to LSU yesterday. I believe that's been delayed. I haven't been able to get a complete confirmation on it.

The availability of funding, Madam Chairman, has been a serious issue. It's made life very, very difficult I know for the people at Brookhaven in terms of getting their part of the program going.

Mrs. **Lloyd.** This is a prevailing mood across the country this year, in all of our national labs and our high energy physics programs.

Dr. Knotek, given your 1988 funding, what are your estimates, and for 1989, to continue with the synchrotron activities?

Dr. **Knotek.** Well, as you are probably aware, the guidance from the congressional bill was given to the Department of Energy and the Department of Energy gave it to Brookhaven Laboratory, and Brookhaven Laboratory gave it to me; but, there is no accompanying money to carry out a program, and what we have been trying to do is use whatever slack we have in the system to keep design efforts moving, keep our contacts with industry moving so that they remain prepared to move if we can get funding in 1989 to proceed.

We plan, as soon as we have signs that there is going to be a funding profile that we can commit to, to get an RFP to the industrial partners such as you see here, of which there are a total of 20; we submitted an ad in Commerce Business Daily, we got 20 responses; this consortium is only one of those consortia respondent.

A total of 28 companies have made up these 20 consortia. They are very large and many of our largest aerospace corporations are ready to move into this area, including Westinghouse, Grumman, General Dynamics, many, many more.

They are ready to respond as soon as some hard funding appears.

Mrs. **Lloyd**. What interactions have you had with the Sematech Group?

Dr. **Knotek**. We have had quite an interaction with the Sematech Group. I am part of a DOE task force on semi-conductor technology, which was formed in response to this, and includes membership from all the national laboratories.

And, we have been involved in all of the activities of Sematech at this point in planning their activities for the next few years.

X-ray lithography is viewed as a Phase III Sematech project and we're laying the ground work to help them get started in that area.

Mrs. **Lloyd**. Dr. Huber, we understand that you are going to be receiving DOD funding in support of the Synchrotron Radiation Center, and it is a good faith commitment of this Subcommittee that you'll receive some DOE funding also.

Has DOE been in touch with you in regard to the 1988 funding for your research activities?

Dr. **Huber**. Well, we have had some preliminary discussions with Mike Knotek about the possibility of working together with Brookhaven on the injector problem for a compact storage ring. We have expertise in the area of low energy injection and we think we can be of help.

Mrs. **Lloyd**. The Armed Services Committee has made a major commitment of $35 million in x-ray lithography. This is an area that the Department of Defense is very interested in moving forward with.

Has the University been involved in planning the Department of Defense activities with Mr. Maynard, or his office?

Dr. **Huber**. Oh, yes. In fact, Mr. Maynard and Mr. Patterson and others from that office have visited the University of Wisconsin and we, in turn, have visited their offices here in Washington and there has been a great deal of communication back and forth and I think—I'm happy to say that they have been very receptive to our input and our suggestions on how their part of the program should be formulated.

Mrs. **Lloyd**. Very good. Thank you very much, gentlemen. Mr. Fawell.

Mr. **Fawell**. Thank you. This question might be addressed to all of the members.

The fiscal year 1988 continuing resolution, I understand, included $12 million in funding for the "Center for Advanced Microstructures and Devices" at Louisiana State University, which would incorporate "a compact electron storage ring for a synchrotron radiation research in the soft x-ray region."

What are your opinions of the quality of the Louisiana State University proposal and their technical readiness to undertake such a center? Any volunteers?

Dr. **Huber**. Let me lead off. That's a hot potato, of course. I think it's fair to say it's basically a greenfield program.

They have no infrastructure in place and, at the moment, they have a nominal person in charge of that, but as far as I know have not hired a director for the facility.

They are attempting to add faculty, but we think in comparison with the programs at the University of Wisconsin, they have a long way to go.

Mr. **FAWELL**. Any other comments? Dr. Knotek?

Dr. **KNOTEK**. Well, I am a member of their Advisory Board so I'm very much aware of what they are doing.

LSU used x-ray lithography in the whole area of microstructure research as one of the great promise in the future, and they very much desire to get into that area.

But, as Dr. Huber says, they are starting with a greenfield, both from a facilities standpoint and in terms of their expertise.

They are trying to draw the proper people to make it work and they certainly are getting a very enthusiastic response from industry who wants to help them get this facility on the ground.

But, that effort, while it will be a training and a research adjunct and complement to this effort to get industry moving and get into competition, it is a support activity rather than something that's going to get us on the ground with commercial hardware very fast.

Mr. **FAWELL**. Yes.

Dr. **DILLON**. From an industrial point of view now, and of course I'm first to admit we're proposing to them so they're our customer and I would like to emphasize the positive aspects of things.

There is no doubt in my mind that you've got real enthusiasm and commitment at several levels at LSU. The other thing is that the real purpose of the LSU was to get, in our minds, additional beam lines so we can begin to get more experience nationwide, and as the beginning of a technology transfer process.

I think that the ability to take, for example in our proposal, warm magnet technology which is what they are looking for, a conservative step, and put it into that environment is an important step for the beginnings of technology transfer.

And they appear, from our perspective, to be very open to assistance from the experts, and I think that the experts are represented at my left here, at this table.

And so, I see some positive things there, but it's clearly been characterized as a greenfield situation, but one where I think there are a lot of positive characteristics also.

Mr. **FAWELL**. Let me just put one further question. If Louisiana State University is technically competent to undertake the construction and operation of a Center for Advanced Microstructure and Devices, then why should it not serve as the focal point for any national X-Ray Lithography program?

Dr. **HUBER**. Let me just make one comment and that is that we think it's important to get going on x-ray lithography now, in 1988, and the LSU ring, at the earliest, would take at least three years to begin operation from the start of construction, and I don't think the country can afford to wait until the LSU ring is finished to get on with x-ray lithography.

Mr. **FAWELL**. Dr. Knotek?

Dr. **Knotek.** I would like to stress that the facility I showed at the beginning of my talk, our UV ring, took a decade to reach that state of operation and to point where it can support IBM's lithography effort, we have 200 people on our staff with 2,000 man years of experience in this area.

Those people are ready to be applied to this problem now. We can get something on the ground in the time it takes to acquire hardware, and unless we do that, we're going to be out of this race. I think it is imperative that we bring every national resource we have to bear on this problem today, and you must do this in an environment where those people have access to the technology and can bring that resource to bear.

Dr. **Dillon.** I think in addition to the arguments which are very valid, that we need to use the existing facilities that we've got to get going. We're really racing against the clock here and we're racing against some very formidable foreign competition.

And, we also need to start looking down the road because I think that there is a very good chance that this is going to be a successful technology, and I think that's why some of the programs like the one that we were talking about at Brookhaven, are developing the kind of light source that you would use in a commercial environment, are critical.

If we want to be positioned five, six years from now, to begin competing seriously with people in both Western Europe and on the Pacific Rim, it's imperative that we proceed in a broad national program.

I see the LSU facility as a part of that and I think it would be to our disadvantage to try to create any single focal point.

Mr. **Fawell.** May I just ask this final question, Madame Chairman? Which semi-conductor manufacturing concerns are currently pursuing X-Ray Lithography? I gather AT&T certainly is. What is AT&T actually doing, Motorola, National Semiconductor Corporation, for instance?

Dr. **Huber.** I think that aside from IBM, as far as we know, and a lot of this work of course is proprietary, the industry activities as of perhaps several months ago is best described as fragmented.

Honeywell is a company which is getting interested in x-ray lithography; DEC is working with Hampshire Corporation, which is a builder of point sources, plasma sources of x-rays; AT&T dropped out of the x-ray lithography program for a while; now we understand they are getting back in, but we don't know the details of their work.

Other companies, Intel, for example, has a small, at the moment, a small program in x-ray lithography, and I could mention a number of other companies, but I think that gives the flavor of what I said, gives the flavor mainly.

It still seems to be fragmented. In my opinion, what is lacking at the moment is a strong signal from SEMATECH that they think x-ray lithography is important and vital, and the company should get into that business as soon as possible.

Mr. **Fawell.** As usual, you hear the Japanese are our competition. I think they are our competition in almost everything, and I believe, Dr. Knotek, you made the statement that they have seven different companies out there coordinating, working together, and so forth, and yet, we're fragmented; we're not able to—is this cultural differences that we, U.S. companies, just can't seem to get together and cooperate, work?

Dr. **Knotek**. Well, the Japanese companies have a very strong vertical integration, which American companies by and large don't.

IBM is vertically integrated to the point where they both develop new technology, they develop hardware, and they go all the way to the mainframes, and it's strictly for their own use.

So, they are fully vertically integrated, but they are about the only one in the industry with the resources to do that, certainly in the United States.

The Japanese have a tradition of being able to target technologies and pass the order directly from the top, and essentially give tasks to members of industry, and they respond.

Mr. **Fawell**. And the top is what?

Dr. **Knotek**. Their industrial government organization overlooks the development of technology. When they give the word, something happens.

The funds flow and the goals are set over a very long term, and it's a very difficult job to set long term goals in American industry because this is a risky business, the payback won't be for five to seven years, and very few are capable to step out and take that jump.

Mr. **Fawell**. Are the funds actually flowing in significant amounts compared to——

Dr. **Knotek**. In Japan?

Mr. **Fawell**. Yes.

Dr. **Knotek**. In Japan the funds are at least $700 million have been pushed into X-Ray Lithography from the government and industrial sources. There are a total of seven consortia in Japan producing the machine—not seven companies, seven consortia, and we may try to get one or two machines on the ground and they will have ten on the ground within 18 months.

Mr. **Fawell**. Thank you.

Mrs. **Lloyd**. Thank you very much, Mr. Fawell. Thank you distinguished gentlemen for being with us today. It is always a pleasure to see you and have you appear before this Committee.

[Questions and answers for the record follow:]

ANSWERS TO
Republican Member Questions for the Record
For the Hearing of March 29, 1988 by

Paul J. Reardon, Vice President & Director of Experimental
Projects, Science Applications International Corporation

for the

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

Hearing on the Department of Energy (DoE)
FY 1989 Authorization Request for
Energy Research and Development Programs

1. The FY 1988 Continuing Resolution included $12M in funding for the "Center for Advanced Microstructures and Devices" at Louisiana State University which would incorporate "A compact electron storage ring for synchrotron radiation research in the soft x-ray region." What is your opinion of the quality of the Louisiana State University proposal, and their technical readiness to undertake such a center?

Answer:

While SAIC has no direct knowledge of LSU's detailed plans for establishing a "Center for Advanced Microstructures and Devices," we believe, from conversations with senior university officials, that LSU intends to aggressively pursue this matter and establish, over the next three to five years, a first rate research capability for "synchrotron radiation research" at LSU.

The basic performance specifications issued by LSU are for a synchrotron light source that would be useful for x-ray lithography research and development as well or for other synchrotron radiation research. We believe, and are quite certain LSU would agree, that all of the infrastructure required to ensure success of a project of this type is not now in place and that significant additional effort is required, either by direct staff expansion in a number of critical areas, or through the involvement of trained and experienced industrial expertise in key areas to ensure that the entire venture succeeds.

The LSU approach is not unlike those of many universities in the early post-World War II era, when many accelerator-based research efforts were launched by a few key individuals. For the most part, those extremely successful efforts provided the basic ingredients for many of today's successful US science programs and, indeed led directly and indirectly to the provision of the synchrotron light sources we are now talking about today. We hope we can help LSU provide some of the requisite infrastructure that does not now exist in order to preserve this tradition.

2. If Louisiana State University is technically competent to undertake the construction and operation of a "Center for Advanced Microstructures and Devices," then why should it not serve as the focal point for any "National X-Ray Lithography Program?"

Answer:

In order to have a successful "National X-Ray Lithography Program," extensive research and development must be done on the equipment that is ancillary to the synchrotron light source itself. In the US, this research is going on now at BNL, Wisconsin University, SLAC , and Cornell, but there is not enough beam time available to do all that is required to prove out production line approaches to the manufacture on 0.25 to 0.50 micron chips. The provision of additional beamlines at LSU will significantly benefit that effort but, since research other than x-ray lithography will also be done at LSU, it may not be the proper focal point for a "National X-Ray Lithography Program." This is an issue that LSU should address with the appropriate DOD and DoE sponsors in concert with BNL, the University of Wisconsin, SEMATECH and others involved in x-ray lithography so that a truly National plan develops. One facility at LSU would not be sufficient to address all of the issues simultaneously as well as do the other research LSU plans to do.

With regard to LSU's ability to undertake the construction and operation of a CAMD, I believe they plan to significantly involve industry and others to provide the required competence.

3. I understand that IBM has ordered a compact synchrotron radiation source from Oxford Instruments in England for x-ray lithography purposes, and plans to install this device at its East Fishkill, New York, manufacturing facilities. If IBM is pursuing this on its own, why should the Federal Government be involved in any way other than providing support for basic research?

Answer:

I do not know in detail IBM's plans for building a complete sub-micron chip manufacturing facility using the Oxford Instruments Light Source or the time frame over which such a facility will operate. From the accelerator point of view, I believe a superconducting storage ring such as that being built by Oxford is basically an R&D system whose performance has not yet been demonstrated. I believe such R&D units should indeed be designed and built but the design of an early sub-micron chip manufacturing plant does not need a superconducting storage ring. In fact, a sufficient synchrotron database for conventional synchrotron light sources already exists for initial layouts of a sub-micron chip manufacturing plant to be made.

The problem is not so much with the synchrotron, it is with the beamline production equipment and that is what needs to be developed more quickly using additional beam ports from new conventional magnet light sources. These conventional magnet storage rings can be built more quickly and, even in the intermediate range, may provide the light sources for first generation plants. The US, I believe, cannot allow the future of this industry to be built solely on the expectation of an important but untried approach being supported by one industry, critical and essential as that industry, IBM, is to the eventual solution of this problem. I think IBM would agree that additional light sources using warm magnet technology should be built in the US to expedite the resolution of tough beamline issues.

4. Which semiconductor manufacturing concerns are currently pursuing x-ray lithography? What is AT&T doing? TI? Motorola? National Semiconductor Corporation?

Answer:

I am not qualified to answer this question.

5. What is SEMATECH's interest in x-ray lithography? Is SEMATECH willing to commit its own funds to participate in the "National X-Ray Lithography Program" and if not, then why should the Federal Government be involved?

Answer:

I believe this question should be answered by SEMATECH. SAIC has not had discussions with SEMATECH on these issues.

6. What is a reasonable schedule for a "National X-Ray Lithography Program" and what are its total costs and yearly costs? What is the proposed funding by agency?

Answer:

I am not familiar enough with all the data to make an intelligent response to this request.

7. What are the critical elements of a synchrotron system for use in x-ray lithography?

Answer:

The most critical elements in the design and development of synchrotron-based light sources are accelerator storage ring reliability and reproducibility of beam characteristics after each storage ring beam fill. Subsidiary issues are long beam lifetimes with associated high vacuum performance; efficient injector systems with reproducible beams, spot sizes and currents; low magnetic field harmonics to prevent beam resonances, active feedback systems to prevent beam blow up, and maintain beam position and clearing electrode systems to extend beam lifetimes. These functions, plus the provision of highly reliable magnets, power supplies, diagnostics, RF systems and controls, are the features of a storage ring that will make it a steady source of x-rays for the production of sub-micron chips. All of these functions are well within the state-of-the-art for conventional magnet synchrotrons.

8. What are the technical barriers, if any, and engineering challenges remaining to be solved in building a synchrotron suitable for use on a semiconductor production line? Please discuss these for both (a) conventional and (b) cryogenic approaches.

Answer:

My response to Question No. 7 covers my view of the situation on conventional magnet separated function electron synchrotron/storage rings. I will only add that if a conventional magnet electron synchrotron/storage ring light source were used to provide the x-ray beams, present designs would need to be optimized for that application which would mean at least a reduction in straight section lengths and lower current coils to reduce operating costs due to power. Other magnet bending and focusing arrangements, such as combined function systems, should also be studied.

The situation with superconducting magnet light sources is more complex. In this case, the number of configurations to be considered is more limited and a combined function solution is probably the most cost-effective although separated function magnetic design can certainly be made to work with more complex cryostats, including independent adjustment features and additional current leads. These machines require very precise magnetic field systems and have limited space for providing diagnostic, magnet harmonic correction devices, feedback systems and access for making changes as a result of operating experience.

In looking at the advisability of using a warm magnet or superconducting magnet accelerator, one really should examine the entire production facility and not overemphasize just the accelerator. In terms of overall plant cost, space for beams, size of plant, flexibility for change, etc., a plant based on warm magnet technology might be superior. In developing pilot plant conceptual designs, in-depth trade-off studies should be made on all approaches (including permanent magnet dipole bending magnets).

9. What are the competing lithographic approaches and competing x-ray sources for x-ray lithography?

Answer:

I am not qualified to answer this question.

10. What other industrial concerns in the US are in the synchrotron building business? In other words, who do you regard as your domestic competitors?

Answer:

I am not aware of all the companies who are interested in building synchrotron light sources and we feel with our partners, General Atomics and Bechtel National, SAIC has the broadest technical capability in the US for designing and building complete sub-micron chip plants using synchrotron radiation x-ray sources. Other companies who have shown an interest in the accelerator systems are: EBASCO Services, Brobeck, Maxwell, General Dynamics, IGC, Grumman, GE, Westinghouse, Titan, etc., and, of course, the European Companies --- Oxford Instruments, Scanditronix, Siemans, COZY Mircotech, ABB, and others. There are also a number of Japanese firms who are capable of building industrial light sources in the US. I mention this because we learned that, in the case of the LSU synchrotron light source, at least one foreign company, Scanditronix from Sweden, has joined an American firm to develop a proposal. Since companies like Scanditronix and several Japanese firms have already built synchrotron light source subsystems or complete systems and no US firms have, we consider them our toughest competitors as there is nothing to prevent them from competing in the US market and using previously engineered designs and manufacturing experience to bid on systems for American companies. In this respect, the IBM experience with the British firm, Oxford Instruments, is an excellent example of the competition American firms face. We hope the US national plan includes some effort to correct this situation and to ensure significant involvement of US industries.

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

Hearing on the Department of Energy (DOE)
FY 1989 Authorization Request for
Energy Research and Development Programs

Republican Member Questions for the Record
for the Hearing of March 29, 1988 for
DR. DAVID L. HUBER, DIRECTOR, SYNCHROTRON RADIATION CENTER
UNIVERSITY OF WISCONSIN-MADISON

1. What is a reasonable schedule for a "National X-Ray Lithography Program" and what are its total costs and yearly costs? What is the proposed funding by agency?

2. The FY 1988 Continuing Resolution included $12 million in funding for the "Center for Advanced Microstructures and Devices" at Louisiana State University which would incorporate "A compact electron storage ring for synchrotron radiation research in the soft x-ray region." What is your opinion of the quality of the Louisiana State University proposal, and their technical readiness to undertake such a center?

3. If Louisiana State University is technically competent to undertake the construction and operation of a "Center for Advanced Microstructures and Devices," then why should it not serve as the focal point for any "National X-Ray Lithography Program"?

4. I understand that IBM has ordered a compact synchrotron radiation source from Oxford Instruments on England for x-ray lithography purposes, and plans to install this device at its East Fishkill, New York, manufacturing facilities. If IBM is pursuing this on its own, why should the Federal Government be involved in any way other than providing support for basic research?

5. What are the critical elements of a synchrotron system for use in x-ray lithography?

6. What are the technical barriers, if any, and engineering challenges remaining to be solved in building a synchrotron suitable for use on a semiconductor production line? Please discuss these for both (a) conventional and (b) cryogenic approaches.

7. What are the competing lithographic approaches and competing x-ray sources for x-ray lithography?

8. What, if any funding does the National Science Foundation provide to your Center for X-Ray Lithography?

9. Which industrial firms are participating in your Center? How much cost sharing is being providing?

10. What is the total level of Federal funding you are seeking for your Center for X-Ray Lithography, and what is the amount you are requesting for FY 1989?

Synchrotron Radiation Center
University of Wisconsin-Madison
3731 Schneider Drive
Stoughton, WI 53589-3097 (608) 873-6651

1988 May 20

Representative Marilyn Lloyd
Committee Chairman
Subcommittee on Energy Research and Development
2266 Raburn House Office Building
Washington, DC 20515

Dear Representative Lloyd:

I am happy to provide you with my responses to the Republican Member Questions for the Record for the hearing of March 29, 1988. I will limit my remarks to questions 1, 2, 5, 7, and 9, which are in the areas that are most familiar to me and answer them in that order.

1. Louisana State University - LSU has requested bids for a conventional storage ring for research in the soft x-ray region. Assuming the project is successful from an engineering point of view, the university is still faced with the problem of developing the infrastructure needed for a successful R&D program in x-ray lithography. At present, there are no LSU staff members actively engaged in x-ray lithography research. Overall, in the Department of Electrical and Computer Engineering, LSU has 22 research projects and $931,000 in research funding. [As a point of reference, the Department of Electrical and Computer Engineering at the University of Wisconsin-Madison has 145 research projects and $4,731,000 in research funding.] To build up a program in the lithography area, LSU would have to hire additional staff and provide them with start-up funds for equipment and graduate students.

2. LSU Leadership - Most government, industry, and university personnel familiar with foreign x-ray lithography programs agree that an aggressive US program must start now if we are to establish a competitive position in this technology. We estimate it would take from three to four years for LSU to procure and commission a storage ring and to implement the beamlines required for x-ray lithography research.

5. SEMATECH is an important potential sponsor of x-ray lithography. It has a Phase III objective of developing IC's with 0.35 micron features in about 5 years. At the present time, SEMATECH is in a start-up mode. Their first concern is to find a CEO, establish definitive Phase I plans, and prepare their Austin, Texas site for the manufacture of memory chips that are to compete with chips being manufactured in

Japan today. Indications are that once the CEO is in place, SEMATECH will begin to move ahead on x-ray lithography.

At a recent meeting of the SEMATECH Lithography Committee, a recommendation was made that, if a storage ring is developed at BNL with an industrial partner, it should be delivered to Austin to support pilot production. As with the LSU machine, it is expected to take from 3 to 4 years before the ring is available for x-ray lithography R&D. In the meantime, R&D in this area should be carried out at existing storage rings such as those at Wisconsin, Stanford, and BNL.

7. The critical concern in the development of a storage-ring based x-ray lithography manufacturing system is to obtain high levels of equipment reliability to ensure around-the-clock operations with less than 5% unscheduled downtime. This will require the careful design and engineering of control systems, magnets, vacuum components, and diagnostic equipment.

9. Optical Lithography using Deep UV Excimer Lasers - It is generally agreed that the limit of optical lithography to pattern large, complex VLSI chips lies in the range of 0.35 to 0.50 microns, although it is unknown what tolerances will be manageable under production conditions. The recognition of this fact was the reason why SEMATECH established their Phase III program goal at 0.35 microns and why Japan and Europe have mounted major programs to develop a 0.25 micron x-ray lithography capability for the manufacture of 64M-bit, and larger, memory chips by the 1990's.

Optical lithography becomes increasingly difficult as IC feature sizes approach 0.50 microns. The operation of an optical system near its theoretical limit seriously degrades the processing latitude required in production to accommodate exposure, focus, and wafer flatness The design of a lithography lens for a given image size a careful trade-off of resolution, numerical aperture (NA), and available optical materials.

Optimistically, one might hope that the production resolution of an optical lithography system might be somewhat better than the usually assumed:

0.8 x exposure wavelength/NA.

Thus the expected production resolution for an excimer laser system with a state-of-the-art 0.4 NA objective lens would be about 0.4 microns. It must be pointed out, however, that it would be extremely difficult to design and manufacture a 0.4 NA lens with a flat, aberration-free image greater than a square centimeter. Future memory chips are likely to be substantially larger.

Direct-Write Electron Beam Lithography - The wafer patterning rate (exposures/hr) projected for the next-generation direct-write electron-beam lithography systems is an order of magnitude slower than the minimum economically acceptable rate for high-volume IC production.

Step and Repeat Aligners with Plasma Sources - Plasma x-ray sources offer the potential for stand-alone x-ray lithography systems. It is likely that plasma x-ray sources will become practical by the early 1990's. However, these systems must overcome a number of disadvantages before they can be considered to be serious candidates for high-volume IC production. Storage ring sources are available now and thus make it possible for the US semiconductor industry to compete with Japan and Europe in the development of critical x-ray mask and IC processing technologies.

I appreciate the opportunity to respond to these questions and thank the subcommitee for its efforts in developing a coherent national program in this vital area.

Sincerely yours,

David L. Huber
Director

cc: J. Dugan

Mrs. **Lloyd**. Now I'd like to welcome a fellow Tennessean, Dr. Joseph Hamilton, Professor of Physics at Vanderbilt University. He is appearing on behalf of the American Association of Universities and the American Council of Education—you wear a lot of hats today, my word—National Association of State Universities and Land Grant Colleges and Association of Graduate Schools and the Council of Graduate Schools. Well, they are certainly well represented and we are looking forward to your testimony. Please proceed, professor.

Mr. **Hamilton**. Are you ready?

Mrs. **Lloyd**. Please proceed.

STATEMENT OF DR. JOSEPH H. HAMILTON, LANDON C. GARLAND PROFESSOR OF PHYSICS, VANDERBILT UNIVERSITY, NASHVILLE, TN, ON BEHALF OF THE ASSOCIATION OF AMERICAN UNIVERSITIES, AMERICAN COUNCIL ON EDUCATION, NATIONAL ASSOCIATION OF STATE UNIVERSITIES AND LAND-GRANT COLLEGES, ASSOCIATION OF GRADUATE SCHOOLS, AND COUNCIL OF GRADUATE SCHOOLS; ACCOMPANIED BY DAVID ARFIN, ASSOCIATION OF AMERICAN UNIVERSITIES, WASHINGTON, DC

Dr. **Hamilton**. Thank you, Madam Chairwoman and Members of the Subcommittee. I am Joe Hamilton, Landon C. Garland Professor of Physics at Vanderbilt University and I am testifying on behalf of the associations which have just been mentioned. These institutions represent the universities where virtually all of our university research programs funded by the Department of Energy and other Federal research-supporting agencies are located.

These institutions represent our nation's capacity to do research and to train young scientists and engineers to the very highest levels. How well they are equipped to carry out their research and education missions and how well they perform relative to our foreign competition ought to be high priority concerns for the Subcommittee and for the Department of Energy. I appreciate very much this invitation to appear before you on their behalf.

The U.S. scientific and engineering system remains strong, but we can no longer take our preeminence for granted. Today our research in education systems are subject to unprecedented international competition and severe internal stresses. Our leadership position is jeopardized by weakened commitments to investment in key fields of science and engineering, including those of direct interest to the Department of Energy.

We are training, I suggest, insufficient numbers of our most talented people at the highest levels in science and engineering at outdated university research facilities and equipment hamper our research in educational programs.

The seriousness of these deficiencies are documented in several recent reports, such as the report, "A Renewed Partnership," which was chaired by Professor Bromley, who spoke earlier. These problems are becoming so critical that unless the steps are taken by this Subcommittee on behalf of DOE to reverse what I see is the downward trends in our university programs, within a decade our nation will face major crisis in its ability to sustain our scientific enterprise. Our universities are the foundations of our basic sciences upon which all our technology depends.

We could look quickly in my documented testimony about various evidences for these declines. For example, the United States has maintained a more or less constant percentage of its R&D of its Gross National Product and we have lagged far behind that of Germany and Japan and that difference is growing.

If we look over the last ten years, the university proportion of the total Federal R&D budget has steadily declined over that period of time. Over the last 20 years, the number of scientists and engineers employed per 100,000 workers in the U.S. work force has remained essentially flat, while those in Japan, France and Germany have nearly tripled in that period.

Recently released were the disturbing comparisons between the science achievements of U.S. students and that of students the same age in 16 other nations. U.S. 10-year-olds, 14-year-olds and high school seniors ranked near the bottom in science achievement, so the decreased interest in science has extended now all the way down to the elementary schools. These are shocking facts about our future science talent pool, and even that pool, as Professor Bromley earlier noted, will decline by 25 percent in the near future.

It is not at all clear that we can hold production of young scientists and engineers at even the present level under current policies and funding priorities. Increased multi-pronged support for university research programs is essential in reversing the task or these trends.

I would now like to hone in on how this inadequate investment in people and instruments and facilities affect us at the grass roots levels, on the campuses—specifically how operating budgets and funds for new equipment for research and graduate training at universities have not grown at sufficient pace to: (a) keep our universities competitive internationally in basic and applied nuclear scientists in the next decade; and (b) to attract sufficient numbers of our best undergraduates into physics to maintain our future.

I will try to do this by providing you with examples from Tennessee and beyond.

Beginning in the 1970's when NSF and DOE funds for research became increasingly limited and the Federal scholarship programs were severely cut back, some alarming trends began that are already having serious consequences and may reach crisis proportions by the mid-1990's unless major steps are taken to reverse the situation.

Already we are losing our cutting edge and superiority in new scientific discoveries and in applications of basic research to the development of our nation. Second, we are cutting off the pipeline of research faculty who are needed to keep our research universities competitive and to turn out the best scientists and engineers, who will in turn be called upon to educate future generations and to run our scientific laboratories. I firmly believe that in the long run this latter is the more dangerous, because if we are to remain a major world power, the demands for scientists and engineers and for a technologically-literate population will continue to escalate as we move towards an increasingly higher-technologically-oriented society.

Let me give one telling antidote from our present path that can be found by examining the career choices of physics students at Vanderbilt University. Since 1975, essentially every 4.0 straight-A student who majored in physics at Vanderbilt has opted for a career in medicine rather than pursue graduate studies in physics. Cynics may contend that is because they can make more money in medicine, and that's true. But that has always been true that they can make more money in medicine. Doctors in this country make more than scientists, but I am convinced that what provoked the turnaround in physics that we have seen at Vanderbilt to medicine as a career rather than physics was the signal from Washington though the cutoff of scholarships, and more important, limits on funds for research that such students no longer had fulfilling careers ahead conducting research in physics.

Why make science a career choice when they saw their established university programs just hanging on and essentially no new young faculty being funded? Indeed, the production of Ph.D.'s in physics is less than half of what it was a few years ago, and this trend, combined with the fact that the number of foreign-born students receiving the Ph.D. in physics has increased over the decade from under 15 percent to about 35 percent will have lasting impacts.

Let me illustrate this point again from my own experience at Vanderbilt. Of the 40 students whom I have trained as Ph.D. thesis in physics, only 5 were foreign nationals, and of those, two returned to their home countries. However, the last two Ph.D.'s from my group were from Malaysia and the People's Republic of China, and of the 6 Ph.D. students currently working in my group, 5 are foreign nationals, all but one of whom are committed to returning to their home universities.

I spoke earlier this week with Bill Burg, the Chairman of the University of Tennessee in Knoxville, and he commented to me—Chairman of Physics at the University of Tennessee in Knoxville—that he had four and a half file drawers filled with foreign student applications for graduate work next year, a third of a file drawer from American applications. In addition, many of the foreign students we train will stay in this country, but many do not have sufficient command of English to be effective as university teachers. Already, when I was Chairman of our department, between 1979 and 1985, as I sought to add several new faculty members, I found it very difficult to even identify candidates of sufficient quality that they could be future leaders in teaching and research in several fields.

As we look ahead, there is going to be a big bulge nationwide in college and university faculty retirements between 1995 and 2005. At Vanderbilt University, approximately half of our faculty physics and astronomy will retire in that decade. The crisis is that we will not have anywhere near the quantity and very much less the crucial top-quality Ph.D. graduates to replace these retiring faculty.

I ask you, is this a satisfactory legacy we would like to leave future generations?

As early as 1970, Vanderbilt and the University of Tennessee physics faculties saw that the costs for doing nuclear science were escalating sufficiently rapidly that only a few major nuclear accelerators would be built in the country. Thus, we began to shift our own campus research work to using facilities at Oak Ridge National Laboratory for our nuclear programs.

We organized a group of 10 universities in the state of Tennessee and Oak Ridge to form the UNISOR consortium, a university isotope-separator project. We did it in such a way that the students and faculty could continue to interact both in the building and the operation of equipment for research. When the new Holifield Heavy Ion Research Facility came in Oak Ridge, Vanderbilt and the University of Tennessee saw that it was essential that this be a university-friendly user facility where faculty and their graduate students could carry out their research and training without sacrifices in quality of research or training. We thus founded the Joint Institute for Heavy Ion Research in Oak Ridge to provide space for outside users and a visitors' program to help people to work at Oak Ridge National Laboratory for extended periods of time. Vanderbilt, the University of Tennessee and the State of Tennessee, along with UNISOR, provided $600,000 of the $1 million for the building for that joint institute.

This institute has set in motion what has become a major shift in the National Laboratories as their accelerator facilities have become increasingly user facilities from scientists from across the nation. The leading laboratory in this move has been HHIRF in Oak Ridge. For example, there has been an average of over 90 U.S. university faculty and graduate students every year from about 25 different universities using HHIRF. In the last four years, 82 different graduate students worked at HHIRF and 47 did most or all of their Ph.D. thesis work at Oak Ridge National Laboratory.

The State of Tennessee and Vanderbilt had provided over 70 percent of the operating funds for the first three years to get our joint institute started. The Institute has pointed the way to the future and has helped to bridge the gap during current tight fundings. However, the State and our universities cannot continue to provide such large fractions of the operating funds. The Federal Government must recognize the new partnerships of its universities and its National Laboratories.

The point of all this is that the DOE National Laboratories, particularly HHIRF, are becoming major training grounds for our nuclear scientists from across the country. The role of these laboratories as extensions of our universities must be recognized and operating support for these facilities and for the universities to use these facilities likewise must be increased.

There is an additional point, however, which has been overlooked. Graduate students and faculty need to have the opportunity to build and develop new equipment. There have been modest new funds from this Committee to help refurbish on-campus facilities at our universities. These funds, I stress, for on-campus research must be expanded, but what about universities using National Laboratories? Currently, the universities are excluded from the new funds to refurbish on-campus facilities, and the budgets for equipment at National Laboratories such as HHIRF this year were cut 30 percent—thus the UNISOR consortium and Vanderbilt have been stymied by this lack of DOE equipment funds even when we had major contributions from our universities to build such. It is essential that there be new funds for universities to build equipment and to replace old equipment for their research needs at the National Laboratories.

The 1989 DOE budget must be reviewed in the context of its trends among other Federal agencies. When that is done, the trends make investing in DOE's research and engineering and training programs all the more critical to sustaining a leadership position in technology-related fields.

However, since 1980, defense-related programs in DOE budget have enjoyed healthy growth patterns, for example, the Atomic Energy Defense Activities increased by 38 percent while DOE's overall R&D budget has fallen by 26 percent in constant dollars. In the 1989 budget, requests for university-related programs for R&D are up nearly 11.5 percent, but most of this increase is stipulated for the Superconducting Super Collider and the Clean Coal Technology initiative. These do not address what I consider to be the real heart of the problems as viewed by the universities.

The basic research programs administered by the Office of Energy Research provide over 85 percent of DOE's total funding of direct awards to universities for the conduct of R&D. It is essential that the Government provide increased support for these programs.

Finally, let me stress again that the Department has requested $5 million for a University Research Instrumentation Program. I would urge this Committee to fund this program at least at the FY 1987 level of $6.2 billion—million, excuse me; that is an error I hope we caught in the published remarks—and to add new funds for university equipment for use at the National Laboratories.

Finally, I would suggest we need new fellowship programs and new funding for young investigators to attract our best young people into science. These are needs as seen from the university grass roots levels. The quality of our nation's future I firmly believe is at stake, and I thank you for this opportunity to testify on behalf of our universities.

[The prepared statement of Dr. Hamilton follows:]

Statement
on the
FY 1989 Department of Energy Authorization

Dr. Joseph H. Hamilton
Landon C. Garland Professor of Physics
Vanderbilt University
on behalf of the
Association of American Universities

and the
American Council on Education
National Association of State Universities and Land-Grant Colleges
Association of Graduate Schools
Council of Graduate Schools

Committee on Science, Space, and Technology
Subcommittee on Energy Research and Development
U.S. House of Representatives

March 29, 1988

Madam Chairwoman and Members of the Subcommittee:

I am Dr. Joseph H. Hamilton, the Landon C. Garland Professor at Vanderbilt University, testifying on behalf of the Association of American Universities, and four other higher education associations. Together, the institutions represented by our associations account for virtually all of the university research programs funded by the Department of Energy and other federal research-supporting agencies. These institutions represent our nation's capacity to do research and train young scientists and engineers to the highest level. How well they are equipped to carry out their research and education missions and how well they perform relative to our foreign competition ought to be priority concerns for this Subcommittee and for the Department of Energy. I appreciate your invitation to appear before you.

Before addressing the specifics of the FY 1989 DOE authorization, I would like to place the DOE research and education programs in context by briefly examining some current measures of how well the United States is doing in the economic, research and education arenas compared to our foreign competitors.

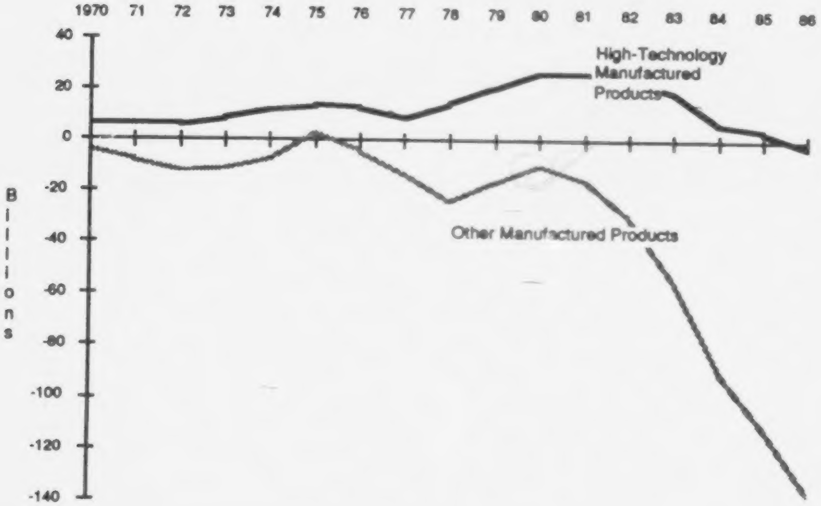
National Investment Patterns

The U.S. scientific and engineering system remains strong, but we can no longer take our pre-eminence for granted. Today our research and education systems are subject to unprecedented international competition and severe internal stresses. Our leadership position is jeopardized by weakened commitments to investment in key fields of science and engineering, including those of direct interest to the Department of Energy. We are training insufficient numbers of our most talented people at the highest levels in science and engineering, and outdated university research facilities and equipment hamper our research and education programs. Evidence that we are losing ground is seen in our negative balance of trade, especially in high-technology products; in the percentage of Gross National Product accounted for by nondefense R&D spending; in the percentage of U.S. patents granted to residents of foreign countries; and in the fraction of our population engaged in research and development.

The following data document several disturbing trends:

1. **In 1986, for the first time in history, the U.S. experienced a trade deficit in high technology goods.**

First U.S. Trade Deficit in High Technology Products

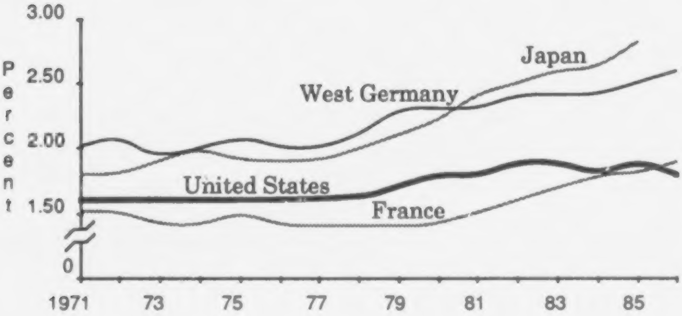


Source: NSF

It is too soon to know whether recent economic and monetary changes will reverse this. However, even if the balance again turns positive, serious underlying difficulties rooted in our research and education enterprise will remain.

2. For 15 years, U.S. investment in civilian R&D as a percentage of GNP ha lagged far behind that of West Germany and Japan, and the difference is growing. France has now passed the U.S.

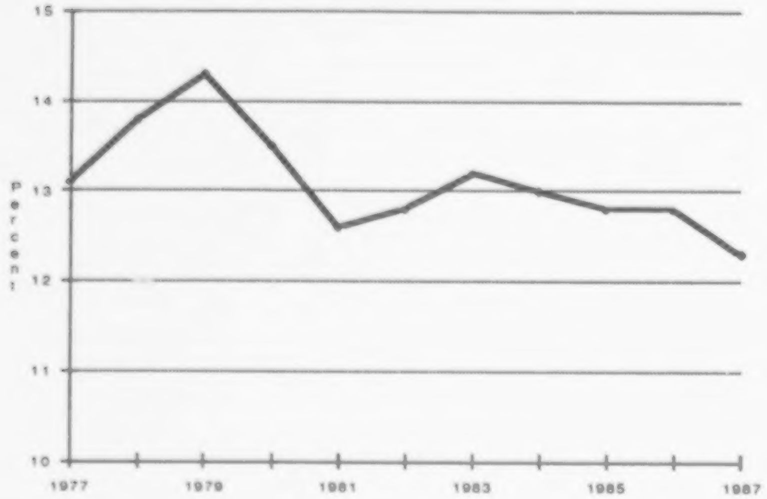
U.S. Trails West Germany, Japan, and France in Non-Defense R&D Expenditures as a Percent of GNP



Source: NSF

3. For ten years the university portion of total federal R&D has declined steadily.

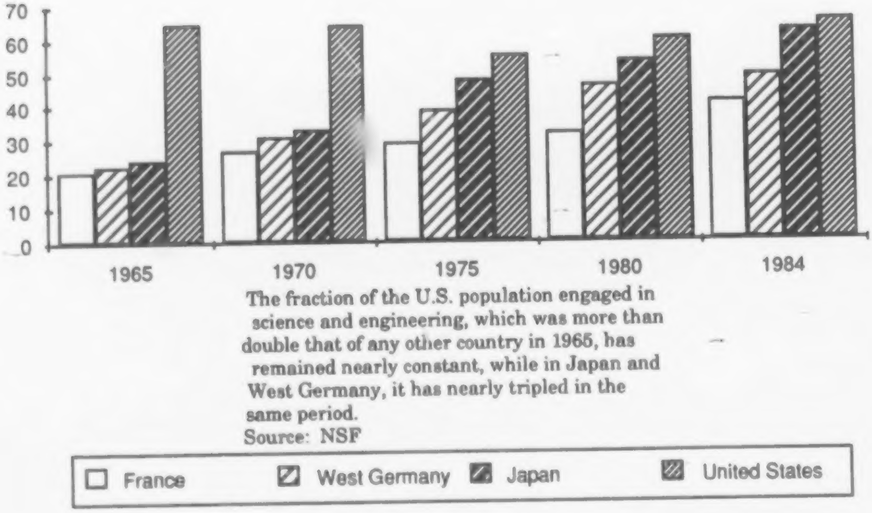
University Portion of All Federal R&D Declines
FY 1977-1987



Source: NSF

4. The number of scientists and engineers employed per 10,000 workers in the U.S. work force has remained essentially flat for more than 20 years, while those of our foreign competitors, especially Japan, have grown substantially. In 1965 the fraction of the U.S. population engaged in science and engineering was more than double that of any other country. In Japan and West Germany it has nearly tripled while the U.S. has stood still. Now the gap between the U.S. and Japan, perhaps our leading foreign competition, has closed.

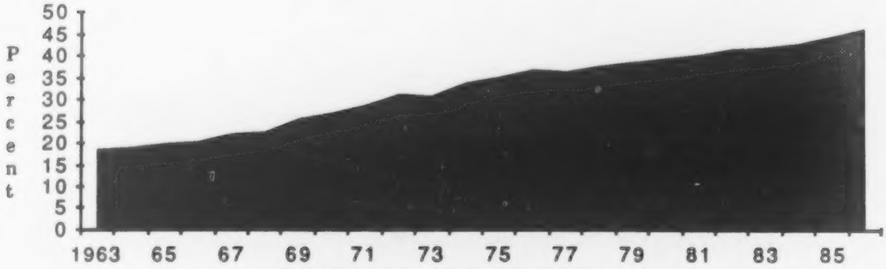
**The Shrinking U.S. Lead:
Research and Development Scientists and Engineers
per 10,000 Workers**



The fraction of the U.S. population engaged in science and engineering, which was more than double that of any other country in 1965, has remained nearly constant, while in Japan and West Germany, it has nearly tripled in the same period.
Source: NSF

5. Almost half of U.S. patents, many in key technologies, are now awarded to foreign citizens. The percentage of U.S. patents granted to residents of foreign countries has increased from 19 percent in 1963 to 45 percent in 1986.

A Measure of a Decline in U.S. Inventiveness and Competitiveness: Percentage of U.S. Patents Granted to Residents of Foreign Countries:1963-1986



The percentage of U.S. patents granted to residents of foreign countries has increased from 19% in 1963 to 45% in 1986.

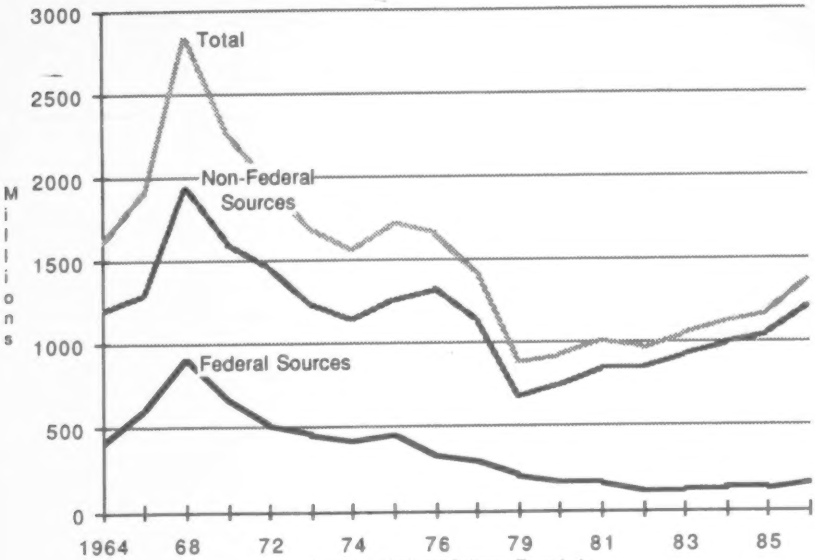
Source: U.S. Department of Commerce

6. With regard to research, the most recent data available from the National Science Foundation show that we allocate a smaller percentage share of our total research investment to engineering, the physical sciences, computer sciences and other key fields than do Japan, West Germany, England or France. Because we support the world's largest research enterprise we still invest far more in absolute dollar terms than our competitors. However, our relative commitment, measured as a percentage share of our total research investment, lags behind that of our competitors in the fields of science and engineering most directly of interest to the Department of Energy.

7. A serious and growing problem remains unaddressed that poses significant adverse consequences for university research programs funded by the Department. As the following figure shows, national investment in the academic plant of universities has declined sharply over the past two decades. Federal government investment has declined by 95 percent over this period, leaving the states and universities to address the problem alone. While universities and states continue to invest in facilities, the

best estimates available to us indicate that institutions are able to meet only about half of their accumulated deficit.

Investment in Research Facilities Declines



Source: National Science Foundation

Meanwhile, the cost of doing research at the frontiers of science and engineering continues to escalate. The nature of research has been revolutionized, and costs have increased dramatically. Microelectronics research, for example, requires clean rooms with air 100,000 times as pure as normal rooms, and floors virtually free from vibration. Modern chemistry and biology require special ventilation and waste disposal facilities. Faculty cannot do large-scale computation without computer rooms with carefully controlled environments. Engineering facilities of many institutions are poorly equipped to conduct modern research and training programs. The consequences of the facilities deficit are measured in lost research opportunities, closed lines of investigation, impeded research, poorer graduate training and a loss of research competitiveness.

8. In precollege education a report recently released by the International Association for the Evaluation of Educational Achievement (IEA) shows disturbing comparisons between the science achievement of U.S. students and that of students of the same age in 16 other nations. U.S. 10-year-olds, 14-year-olds and high school seniors rank near the bottom in science achievement. Some will argue that the differences among the educational systems of the nations surveyed and the unique commitment to universal education in the United States explain the results, and they are correct to point out these important differences. However, such explanations fail to respond fully to the conclusions of the IEA report, especially when the educational achievement of our students is placed in the context of our future talent pool.

How Do We Rank?
Student Achievement in Science

	Grade 4/5	Grade 8/9	Grade 12/13 Science Students		
	Age 10	Age 14	Biology	Chemistry	Physics
Australia	9	10	9	6	8
Canada*	6	4	11	12	11
England	12	11	2	2	2
Finland	3	5	7	13	12
Hong Kong	13	16	5	1	1
Hungary	5	1	3	5	3
Italy	7	11	12	10	13
Japan	1	2	10	4	4
Korea	1	7	—	—	—
Netherlands	—	3	—	—	—
Norway	10	9	6	8	6
Philippines	15	17	—	—	—
Poland	11	7	4	7	7
Singapore	13	14	1	3	5
Sweden	4	6	8	9	10
Thailand	—	14	—	—	—
USA	8	14	13	11	9
Total number of Countries	15	17	13	13	13

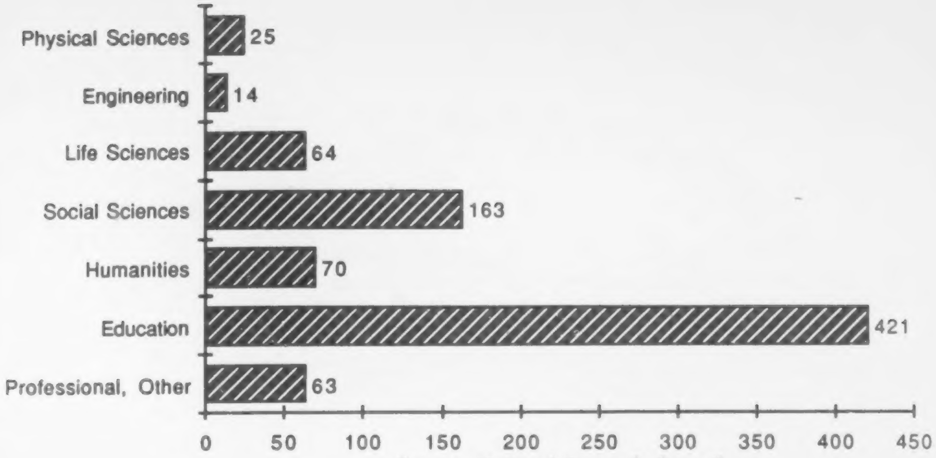
Source: Science Achievement in Seventeen Countries, International Association for the Evaluation of Educational Achievement, 1988.

* English-speaking Canada

9. Between now and early in the next century, the traditional college-going 18-to-22-year-old group of Americans will decline by 25 percent. We simply are going to have fewer undergraduate students of traditional college age. Some note that total enrollments could remain near current levels because older students are pursuing college educations in greater numbers, and by itself this is an encouraging development. However, most of our future engineers and scientists will continue to come from the traditional college age populations, and that population base will continue to shrink. We will have to double our current yield from among the traditional undergraduate population if we are to hold production of young scientists and engineers at even present levels. It is not at all clear that the job can be done under current policies and funding priorities, in large part because we are failing to attract to graduate programs in science and engineering sufficient numbers of women and minorities, especially blacks and Hispanics. Blacks and Hispanics currently make up about 20 percent of the total U.S. population, but they account for less than 2 percent of doctoral degrees in science and engineering. By 2020, these groups will make up one-third of the U.S. population.

10. With regard to the granting of Ph.D.s to minorities and women in the sciences and engineering, we are no longer making progress or even holding our own. We are losing ground. Consider the implications of the following figure which shows the small number of Ph.D. degrees awarded to black students. In 1986, 25 black students earned the Ph.D. in the physical sciences; only 14 blacks received the Ph.D. in engineering.

Ph.D.s Awarded to American Blacks in 1986



Source: National Research Council

11. The picture with regard to women is not much brighter. A few years ago the number of women pursuing graduate degrees in all of the major professions (law, medicine, business and engineering) was in the low single digits. Now about one-third of students in law, medicine and business are women. But in engineering, the percentage of women students has increased to only about 6 percent. Women earn only about 16 percent of Ph.D.s in the physical sciences and 15 percent in mathematics. The reasons for this are complicated and not entirely understood, but the fact is that we are failing to attract and retain sufficient numbers of women in graduate programs in engineering, mathematics and the physical sciences.

12. More generally, we are failing to attract sufficient numbers of U.S. citizens into graduate education in engineering. Between 1970 and 1985 the number of Ph.D. degrees in engineering awarded to U.S. citizens declined by 50 percent. Our dependence on foreign nationals as faculty in our engineering schools is well documented and widely reported. Now 50 percent of assistant professors in engineering are foreign nationals, compared with 10 percent in 1970.

We must continue to welcome foreign students and educate them. It is in our interest as well as theirs that we do so. About 40 percent of the engineers (and 60 percent of the computer scientists) remain here to work in our universities, industry and government and are among the most productive members of our society. But the fact remains that we are, quite simply, failing to attract a sufficient number of our own students into graduate programs in engineering and the sciences. Present incentives provided through existing federal fellowship and traineeship programs are insufficient to compete effectively in the marketplace for our most talented young scientists and engineers. The graduate fellowship program sponsored by the Office of Naval Research is perhaps the strongest program of its kind offered by any federal research agency, including the NSF and DOE, but ONR makes only about 50 awards per year. The Department of Energy has made several attempts to establish a similar program, but has not yet been successful. As a point of departure, we recommend that the Subcommittee establish a pre-doctoral program for entering graduate students, which would complement the existing support provided by the department principally at the dissertation stage. Such a program should be portable -- the student carries the fellowship to the institution of choice -- and should provide stipends which will attract the requisite talent.

Role of Universities

All of our national policy objectives depend heavily upon graduate education, both for highly trained personnel and for advances in scientific and technical knowledge that will allow us to develop alternative sources of energy that are necessary to sustain our economy and to ensure our defense. It is our graduate schools that provide the continuing supply of talented individuals with the knowledge, technical skills and perception that equip individuals to meet the challenges of this complex and technologically sophisticated age.

The federal government is and necessarily will remain the single largest patron of university research and research training, and, as such, bears an important share of the responsibility for sustaining a vigorous research base at universities. Unfortunately, the government has not maintained a balanced investment in that research base since the late 1960s. As a consequence, our research universities have accumulated serious deficits in four areas: research facilities, research instrumentation, graduate education, and young faculty investigators. This conclusion is articulated by the following statements by the White House Science Council, NSF Director Erich Bloch, and National Academy of Sciences President Dr. Frank Press:

> Our universities today simply cannot respond to society's expectations for them or discharge their national responsibilities in research and education without substantially increased support.
>
> White House Science Council Panel on the
> Health of Universities and Colleges report,
> A Renewed Partnership.

> I cannot emphasize enough the importance of beginning immediately to do everything we can do to strengthen the Nation's scientific and engineering effort. A well educated and trained scientific and industrial work force, along with the modern facilities and equipment necessary to be most productive, is mandatory if we are to maintain and enhance the nation's position relative to our trading partners abroad.
>
> Mr. Erich Bloch
> Director
> National Science Foundation

> There are serious stresses in investment, on human resources, and on the main pillar in the American Research system--the university. The United States has the biggest research budget in the world; but it also supports the largest research enterprise, and is doing so inadequately. Proposals judged excellent cannot be funded. Grant sizes are too small. Instrumentation in university laboratories is often obsolescent. There is virtually no federal facilities program as there was in the fifties and early sixties.
>
> Dr. Frank Press
> President
> National Academy of Science

For these reasons, we ask the Subcommittee to provide the Department with whatever additional authority or direction may be required in order to restore the Department's programs to appropriate levels consistent with the Nation's needs.

A View from the Campus

Madam Chairwoman, I would now like to address how this inadequate investment in people, instruments and facilities, affects us at the grass roots level: the campus. Specifically, I will address how operating budgets and funds for new equipment for research and graduate training at universities have not grown at a sufficient pace to: (a) keep us competitive internationally in basic and applied nuclear sciences in the next decade, and (b) attract sufficient numbers of our best undergraduates into physics to maintain our future. I will try to do this by providing you with examples from Tennessee, the South, and beyond.

I am a principal investigator of a DOE grant in experimental nuclear physics. My research has produced over 300 publications in journals and another 200 in books. This research has produced significant advances in our understanding of the nucleus of the atom. At Vanderbilt, I have directed 25 M.S. and 40 Ph.D. graduate student theses and trained over 80 postdoctoral fellows. Overall my group has produced 40 M.S. and 60 Ph.D. theses. These graduates occupy positions of leadership in universities, colleges, government laboratories, DOE Headquarters, industries and hospitals in at least 20 states and over 20 foreign countries. Many of my former Ph.D. students have, in turn, directed their own M.S. and Ph.D. students at major universities, thereby producing an impressive multiplier effect. Without question, these people have made significant contributions to our nation's economy and security, several orders of magnitude beyond the modest support provided by NSF and DOE.

People

Beginning in the 1970s, when NSF and DOE funds for research became increasingly limited and the federal scholarship funds were severely cut back, some alarming trends began that are already having serious consequences, and these will surely worsen by the mid-1990s unless steps are taken to reverse the situation.

The consequences of the slow-down in research funds and cut-offs in federal scholarship are two fold. First, we lose our cutting edge and superiority in the applications of basic research. Second, we constrict the pipeline of research faculty needed to keep our universities competitive. I firmly believe that, in the long run, the latter is more dangerous, because if we are to remain a major world power, the demands for scientists and engineers and for a technologically literate population will rapidly escalate as we move toward an increasingly high-technology oriented society.

One telling anecdote of our present path can be found when examining the career choices of our students. Since 1975, essentially every 4.0 (straight-A) student who majored in Physics at Vanderbilt has opted for a career in medicine, rather than pursuing a graduate degree in physics. Cynics may contend that is because they can make more money in medicine. True, they can, but it has always been true that medical doctors make more money in this country than scientists. I am convinced that what provoked the turn from physics to medicine as a career was the signal from Washington, through the cut-off of scholarships and, more important, limits on funds for research, that such students no longer had fulfilling careers ahead conducting research in physics.

Indeed, the production of Ph.D.s in physics is less than half of what it was only a few years ago. This trend, combined with the fact that the number of foreign-born students receiving the Ph.D. in physics has increased from under 15 percent to about 35 percent, will have a lasting impact. Thus, although we continue to train sufficient numbers of scientists and engineers to keep our existing system operating for awhile, it is clear that the science community continues to lose an increasingly higher percentage of the very brightest young minds. Let me illustrate this point, again using my experience at Vanderbilt. Of the 40 students who received Ph.D.s from me, only five were foreign nationals and, of these, two returned to their home countries. However, the last two Ph.D.s from my group were from Malaysia and the People's Republic of China, and of the six Ph.D. students currently working in my group, five are foreign nationals and all but one are committed to returning to their home countries. In addition, while some of the foreign students we train will stay in this country, many do not have a sufficient command of English to be effective as university teachers. This shortage of talent naturally extends down the pipeline. When I was Chairman of the Department of Physics and Astronomy from 1979 to 1985, I sought to add several new faculty members and found it difficult to even identify candidates of sufficient quality that they could be future leaders in teaching and research in several fields.

As we look ahead, there will be a big bulge in college and university faculty retirements between 1995 and 2005. However, we will not have anywhere near the quantity and very much less the crucial top-quality Ph.D. graduates with which to replace these retiring faculty. At Vanderbilt, approximately half of our present faculty in physics and astronomy will retire in that decade. I ask you, is this a satisfactory legacy we would like to leave for future generations?

Equipment

Much has been said about the serious erosion of equipment for research in our universities and, indeed, it is a very serious problem. However, in nuclear science there is an additional problem that has gone unrecognized, and is equally as disturbing. The cost to upgrade and build a major new accelerator facility which is competitive internationally for basic nuclear science has become so great that only limited numbers can be upgraded or built. A few major facilities operated by NSF and DOE remain on university campuses such as those at Florida State University, Indiana University, Massachusetts Institute of Technology, Michigan State University, University of Rochester, Texas A&M University, University of Washington, and Yale University. However, several of these are operated as national laboratories, and all of them are making extensive overtures to other universities across the country to be user facilities for their faculties.

As early as 1970, Vanderbilt and the University of Tennessee physics faculties were already shifting from on-campus research to using facilities at Oak Ridge National Laboratory for their nuclear research work. We saw this as a coming trend and began actively to develop Oak Ridge National Laboratory as a place for universities to do their research. We organized a group of 10-universities, the State of

Tennessee, Oak Ridge Associated Universities and Oak Ridge National Laboratory to form the University Isotope Separator at Oak Ridge, (UNISOR), consortium. We did not want to give up our role in graduate education and research, in which graduate students and faculty interact in building and operating equipment for research. We raised funds to procure a major piece of equipment to be owned and operated by the universities. This has been an extremely productive and cost effective way of keeping these universities involved in forefront research.

When the next new heavy-ion accelerator was started at a national laboratory by DOE in 1975, the Holifield Heavy Ion Research Facility (HHIRF), in Oak Ridge (named after former Congressman Chet Holifield), Vanderbilt and the University of Tennessee saw that it was essential that this be a "university-friendly" user facility. By this we mean a place where faculty and their graduate students could carry out their research and student training without sacrifices in quality of research or training, including the building of new pieces of equipment for research with the accelerator. Thus, we founded the Joint Institute for Heavy Ion Research in Oak Ridge. Vanderbilt, University of Tennessee, the State of Tennessee, and UNISOR provided $600,000 of a $1,000,000 building for the Joint Institute, which is located next to HHIRF. The Joint Institute provides on-site living quarters, offices, secretaries, and a conference center for students and faculty doing experiments at HHIRF. This set in motion what has become a major shift in the national laboratories, as their accelerator facilities increasingly have become user facilities for scientists from across the nation and around the world. The leading laboratory in this move is HHIRF. For the last several years now, there has been an average of over 90 U.S. university faculty and graduate students from about 25 different universities using HHIRF for their research. In the last four years, 82 different graduate students worked at HHIRF and 47 did most or all of their Ph.D. thesis research work at HHIRF. In the case of Vanderbilt and the University of Tennessee, the students live in Oak Ridge for a period of 1-2 years. Currently HHIRF is by far the national leader in being a university-used facility, in large measure because of UNISOR and the Joint Institute. Now, all the national laboratories are making serious efforts to expand their university usage. In addition, the Joint Institute, at which Chairwoman Marilyn Lloyd spoke at the dedication ceremony, has a distinguished scientist visitors program funded primarily by the State of Tennessee with support from Vanderbilt and DOE. Last year there were 48 visitors from around the world who spent an average of two months at HHIRF. The State of Tennessee, through the University of Tennessee and Vanderbilt University, have provided over 70 percent of the operating budget for the Joint Institute during its first three years. However, the state and the universities cannot continue to provide that level of support without additional help from the federal government. Cooperative ventures such as the Joint Institute have helped bridge an existing gap in times of tight budgets. It is now time for the federal government to recognize this enhanced cooperation between universities and the national laboratories, and to provide the support needed to continue.

The point is that the DOE national laboratories, particularly HHIRF, are becoming major training grounds for our nuclear scientists from across the country. The role of these laboratories as extensions of our universities must be recognized and operating support for these facilities likewise increased. Of course, there must be increased research grants to universities for their faculties and graduate students to use the national laboratories for their research. But there is an additional, important point which has been overlooked. Graduate students need to have the opportunity to build and develop new equipment. There have been modest new funds from Washington to help refurbish on-campus facilities at our universities. Those funds for on campus research must be expanded. But, what about universities research at national laboratories? For example, Vanderbilt, Tennessee, and Oak Ridge National Laboratory together built a $2 million Spin Spectrometer to which Vanderbilt contributed $125,000 and the University of Tennessee $350,000. However, we currently are excluded from the new funds to refurbish universities and the budgets for equipment at national laboratories such as HHIRF have been cut by 30 percent. Thus, UNISOR and individual projects which Vanderbilt has proposed to build have been stymied by this lack of DOE funds, even when we have major contributions from our universities to build them. If these conditions persist, we will not be able to continue to provide the proper training for our graduate students; there needs to be increased funds for universities to build new equipment and replace old equipment for their research at the national laboratories. This very important area needs immediate attention.

Facilities

Several nuclear scientists have moved into the field of material science, where nuclear accelerators are used to help develop new materials needed in high technology. However, our efforts nationally in the use of nuclear accelerators in our universities in areas such as materials science are lagging seriously behind the rapidly expanding efforts of other nations. The paucity of such new ventures in our universities is alarming. Japan has mounted massive efforts in which its universities, government and private sector cooperate in this area. If we are to keep from falling behind even more seriously in this high-technology field, we must invest in more university-based research facilities that train scientists and produce innovative research.

FY 1989 DOE Budget Request

The FY 1989 DOE budget must be viewed in the context of the trends in other federal agencies involving key fields of science and technology. DOE, along with NSF and DOD, are the primary custodians of federal investment in fundamental research in engineering and the physical sciences. Recent DOD and NSF policies, however, have pressured DOE to carry a greater share of responsibility for investment in these fields. Last year's Administration proposal to rapidly expand investment in NSF research programs was rejected by Congress, leaving NSF core research programs flat in constant dollar terms since 1985. Last year, budgets for several NSF research programs of direct interest to DOE, such as superconducting materials, failed to keep pace with inflation, and many investigators found their research projects cut below previously awarded levels. These trends make investing in DOE's research, engineering and training programs all the more critical to sustaining a leadership position in technology-related fields.

Since 1980, defense-related programs in the DOE budget have enjoyed healthy growth patterns, with atomic energy defense activities increasing by 38 percent, while DOE's overall R&D budget has fallen by 26 percent in constant dollars. Although this Administration did not succeed in its previously stated goal of dismantling the Department of Energy, civilian research has, on the whole, suffered a real decline of 57 percent since 1980. This includes reductions of 59 percent in fossil energy R&D, 46 percent in magnetic fusion and a nearly 90 percent real drop in renewable energy research.

I turn to the Department's FY 1989 budget request for university-related programs. The FY 1989 budget request for Energy R&D is $6.46 billion, up nearly 11.5 percent over the FY 1988 level, with most of the increase stipulated for the Superconducting Super Collider and the Clean Coal Technology Initiative. Defense-related R&D constitutes 47 percent of the proposed budget.

The basic research programs of the Department of Energy have made and continue to make significant contributions to this nation's technological advancements and, in the process, train the graduate students who will carry forward the nation's research and development efforts. The programs administered by the Office of Energy Research (OER) provide over 85 percent of DOE's total funding of direct awards to universities for the conduct of R&D. These programs support important long-term basic science in several disciplines including high energy and nuclear physics, as well as the computer, material, chemical, engineering, biological and mathematical sciences. It is essential that the government continue to provide steady support for these programs.

The FY 1989 budget proposal provides $375.6 million for the Basic Energy Sciences Program, a $57 million (13.2 percent) reduction from the FY 1988 level. This request is inconsistent with a policy to enhance our nation's science and engineering capabilities. The budget requests $15.8 million for the University Research Support line, a 14.1 percent reduction from the current year. The Department also proposes to end the nuclear engineering research and education program. I urge you to continue to fund this program.

The Department requests $5 million for the University Research Instrumentation program, begun in FY 1984 as a response to the pressing need to upgrade university instrumentation and equipment. In FY 1986, this program was funded at $6.2

million and has enabled several schools to upgrade their capabilities. In light of the needs for equipment addressed earlier, I urge the Subcommittee to fund this program at least at the FY 1987 level of $6.2 billion.

The research capital deficit continues to be the most pressing problem facing universities. As evident from the earlier graphic, for twenty years, no federal research agency has reinvested broadly in the modernization of university laboratories engaged in competitive research programs. There are currently several initiatives pending before Congress which would authorize a national, merit-based, matching grant program. On behalf of the associations I represent today, I urge your support for a national, merit-based, federal matching program to revitalize our nation's research laboratories.

The Department also proposes a new accounting structure which provides a separate appropriation for major "user facilities" entitled the Basic Research User Facilities (BRUF). This line provides for the construction, operation, and maintenance of several expensive and complex federal facilities in the energy sciences, including the Superconducting Super Collider (SSC). The Department requests $972.6 million for the BRUF line, with the largest area of growth being found in the proposed SSC. We support the initiative to build the SSC, and the contributions which the world's highest energy particle accelerator would provide to the scientific community.

Finally, a few words about an issue which has received an extensive amount of media attention, and directly affects the Office of Energy Research. According to the Department, there are 19 university-related, congressionally mandated projects with the Office of Energy Research totalling $143.5 million. These congressional add-ons are directed both for construction of facilities and for research and operating expenses.

We believe that maximum return on investment is an essential goal in the decisions for allocating limited research funds. All research funds should be awarded on the basis of scientific merit in open competition from all interested and qualified parties. Final judgments ought to be formed in an objective and informed manner, free from any actions by particular individuals or institutions that could serve to make the award of such funds a matter of political influence rather than the quality of the work to be done and the capacity of competing applicants to carry out the work at the highest level. With this objective in mind, I urge members of this Subcommittee do everything you can to insist that decisions about funding be guided by the goal which I know we share -- the need to produce the highest quality science and engineering of which we are capable as a nation.

In closing, I urge this Subcommittee to provide DOE with the tools it needs to fulfill its part of the federal role in maintaining U.S. leadership in science and technology. Universities will continue to play a critical role in this endeavor and, therefore, merit support.

Thank you, Madam Chairwoman, for the opportunity to appear before the Subcommittee this morning. I shall be pleased to respond to your questions.

DISCUSSION

Mrs. **Lloyd**. Thank you very much for your excellent testimony. You also provided us with some very valuable statistics and it's true we are certainly getting what we paid for, that we aren't making an investment in it and I think you make a good case that what we put into R&D programs parallels our growth in our gross national product as well.

I was looking at your chart on page 9, Professor Hamilton. You were ranking the comparisons between the United States students and the foreign students. Are these rankings obtained from performance on the same standardized international test, or what is the basis of ranking our 10 and 14 year olds and the Grade 12 science students? I would like for you to clarify that.

Dr. **Hamilton**. Well, I don't know that I can give you the exact details, although perhaps our representative, David Arfin, from the——

Mrs. **Lloyd**. He will enlighten us.

Dr. **Hamilton** [continuing]. Who developed those statistics for me.

Mrs. **Lloyd**. If you will identify yourself and just come up to the microphone—if you would just identify yourself for our recorder.

Mr. **Arfin**. David Arfin, Association of American Universities. These statistics were recently released in the report documented here and they were from similar tests given in the various countries shown. They are startling indeed.

Mrs. **Lloyd**. Very good. One thing that is of great concern to me is that we have virtually eliminated our summer science camps. I believe that if we turn the child in the way he should go that we just really aren't providing the stimulation of the interest in science and any type of basic research. We are not doing enough to really provide a stimulus for bright young people in our country and it seems to me that we do need more such programs for our high school students and undergraduate students in science and all those contemplating graduate school as well.

Don't you think it might be well if DOE, the National Science Foundation, and NASA might invest some matching money with universities to conduct such camps around the nation?

Dr. **Hamilton**. Very much so. Our universities would be a very natural place for many of these young people to come on various occasions. For example, during spring break I gave a lecture for an hour to a group of what are called certified gifted young people in the middle school from Franklin, Tennessee. Several times during the course of a year we will invite people of this nature. But that one time shot, while it gives them some impetus at the point, you need sort of a steady, continuing kind of program, and a summer program would be very valuable beginning at least at the middle school level, because it is at that point at which the turnaround is going to have to start beginning. I am convinced of that both from the fact that I have just had two children and have one child in middle school at the present time, and I see the problems that have developed in our science education system from a first-hand perspective.

Mrs. LLOYD. Of course, it is not on the intellectual level, but I think it is a good example—I sent my boy to Huntsville and the space camp last week. It was a very expensive camp and it was a pretty big bite and not all young people, bright people, can afford this type of stimulation, so I am very interested in seeing what can be done for more summer camps and more intellectual involvement in the summertime.

What do you think of using our national laboratories in such a way? Let's use Oak Ridge as an example, since it is a national laboratory we are both familiar with.

Dr. HAMILTON. Okay. Again, you probably know the University of Tennessee has introduced a program through its Science Alliance Program for undergraduate students to use Oak Ridge National Laboratory and they have something like now 20 fellowships a year which will bring together both the university scientists and the National Laboratory scientists in that program.

I would suggest that a program in which you would do that kind of effort but would bring in not only the National Laboratory scientists but the fact that there are significant numbers of university scientists using the National Laboratories that a cooperative program that would involve both of those would give the students a perspective on what science is about that would be unique in the country, in the sense that they would see the National Laboratories which approach both the basic and some applied areas of research and see the universities using those facilities would be a very exciting opportunity for young students. So if you had some cooperative kinds of programs involving both of those people in a National Laboratory such as Oak Ridge, this would be a very exciting package.

Mrs. LLOYD. I don't think the fact that you have international students that are coming over here is a happening. I think there is a reason.

Mr. HAMILTON. Of course.

Mrs. LLOYD. I think at an early age that these bright people became interested in science and using their intellect and perhaps at an early age we are making the bad decisions and that's a result of what you are seeing as well.

Your comments about nuclear energy engineering are well appreciated, certainly by this Subcommittee because we have been working for seven years to have some reasonable level of funding to support nuclear engineering departments and also the nuclear engineering department heads—its organization— has been helpful in getting the message across to Congress.

Would you comment on the need to get such organizations involved in getting across this message to the Congress? I mean clearly I think we are at a critical juncture that this is an area that must receive the attention of the Congress.

Dr. HAMILTON. Well, you know, one of the things that I am impressed about is—and I am depressed about—is the quality of the available faculty pools in engineering and science courses as we approach the next decade. I have been painfully aware of it in the past week, as I have said, on the tenure and promotion review committee for the university and seeing the promotions that have come forward from the engineering school as well as the rest of the University, and there are just serious difficulties in already finding the significant qualities of faculty to teach our future students. That is just going to escalate in the next decade when large numbers of retirements will take place across the board in engineering and science beginning about 1995 to the year 2005.

Yes, I think that the message is going to have to be made by these associations and by individual faculty members who have seen that first hand. It is a national crisis. We need to face it.

Mrs. LLOYD. And some people are going to have to start pounding their fists on the table and getting involved.

Dr. HAMILTON. And when I say that we need to make some turnarounds, I am serious about it, and it has depressed me no end to see how many bright, talented Vanderbilt students have gone into medicine. That is good for medicine, but it is bad for physics.

Now you might say, you know, I reflected on some of the comments that you missed earlier but which other members of the panel heard from Professor Bromley. Professor Bromley at Yale is an example of the kind of success story we can have across the country if we are willing to supply the new facilities and new increased operating funds that we need desperately in nuclear science for our universities. Across the board we could have those kind of success stories in attracting new students into science if we in fact had that kind of new facilities and the opportunities to keep all of our universities more invigorated.

Part of that is going to have to be done by providing funds for universities to use our National Laboratories because we are not suggesting there is any way we can fund new accelerators the way that we have funded the beautiful new accelerator at Yale. It is important that a few major universities have those on-campus facilities but it is also important that a large number of other universities have sufficient operating funds and sufficient access to university equipment funds to carry on programs at our National Laboratories, and those are parts of what it is going to take to do that kind of turnaround in attracting more Americans into science. Already we have seen at Yale as Professor Bromley has pointed out, that those new facilities have been very significant in attracting the best students at Yale University into their program. That can be duplicated around the country if the funds are made available for other new instrumentations; it doesn't necessarily have to be on the scale which we put funds into Yale—modest funds for detector facilities, other kinds of equipment that will be used at national accelerator laboratories can be crucial in those turnarounds as I see it from the standpoint of our universities.

Mrs. LLOYD. Thank you very much.

Mr. Morrison?

Mr. MORRISON. I try to step back just a little ways and I guess maybe the part about your testimony that has the greatest concern for me is have we really undercut our university system with the creation of the National Laboratories, and is there a way to force greater cooperation between those facilities so that, for instance, maybe people out of the Laboratories could be brought back on the university system for these teaching posts that you are concerned about filling?

Dr. Hamilton. I don't think that is the case. I think the beautiful arrangement that we have at the Holifield Heavy Ion Research Facility in Oak Ridge is an excellent example of what universities and national labs can do in a cooperative kind of venture and not only that but it is exciting for the students as well. Some people say, well, the students don't want to do travel, but in fact it gives them an exciting opportunity. They have access to scientists who are doing pure research at a National Laboratory. They have access to university professors who are doing both teaching and research and they see from that perspective then a variety of the best of our scientific ventures, and that expands the horizons which our students have today.

I would say that what we need to do more of is take recognition in nuclear science of the fact that this kind of cooperation can be to the benefit of our nation as well as our universities and if there are funds available for the universities, you know, for example we have in a proposal right now from Vanderbilt, and Mr. Stallings has now left, but from the Idaho National Engineering Laboratory it is a cooperative proposal by these two institutions, Vanderbilt and INEL, as well as LSU. We want to build a new piece of apparatus at Oak Ridge. The university research funds which have been made available currently are for on-campus research, and that pot of money is excluded to us. There is not a pot of money available for universities like Vanderbilt who want to make use of and who can make effective use of national laboratories in our training programs.

Essentially, of my 40 Ph.D.'s in some fashion or another, almost all of them made use of Oak Ridge National Laboratory in some way. In the early days they produced their radioactive isotopes, which they brought back to Vanderbilt University. Now we are doing accelerator-based physics and so all of them make use of the accelerators either at Oak Ridge or at one of the other National Laboratories for their research work.

I think that kind of cooperation can in fact strengthen our universities and have a very positive benefit on it and I think in fact given the constraints on funds, that is the only way we can go because we can't build all the major accelerators that are necessary to train all the nuclear scientists which we need, but I think this kind of cooperation can be very effective in it.

Mr. Morrison. Thank you.

Mrs. Lloyd. Thank you very much, Professor Hamilton, and we hope we can continue to work along this line, and maybe we can think up—dream up some new incentives to try to create more interest in these very valuable programs for our nation.

Dr. Hamilton. Thank you very much.

Mrs. Lloyd. Thank you.

PANEL 2: ENERGY R&D PROGRAMS

Our next witnesses will appear as a panel: Mr. Timothy Dowd, Executive Director of the Interstate Oil Compact Commission; Mr. Paul Ayres, Babcock and Wilcox; and Dr. James Hartnett, University of Illinois at Chicago.

And Congressman Hall has graciously consented to chair this, and I'll put on another hat and go back to the Armed Services Committee markup.

Thank you very much for being here. Please proceed.

STATEMENT OF W. TIMOTHY DOWD, EXECUTIVE DIRECTOR, INTERSTATE OIL COMPACT COMMISSION, OKLAHOMA CITY, OK; ACCOMPANIED BY DR. CHARLES MANKIN, DIRECTOR, OKLAHOMA GEOLOGICAL SURVEY

Mr. Dowd. Thank you very much, Madam Chairman.

I'm Timothy Dowd. I'm the Executive Director of the Interstate Oil Compact Commission. Before I get into my regular testimony, I'd like to make two brief comments.

The first one is that I am absolutely awed by the breadth of matters that this Subcommittee has to deal with. My mind boggles at having to absorb all of this knowledge that you members do.

Secondly, I have asked to sit in with me, because he was in town, somebody that probably ought to be doing the testifying instead of me, and that is Dr. Charles Mankin, who is Director of the Oklahoma Geological Survey and is Chairman of the Board of the Mineral and Energy Resources, the National Academy of Sciences, and a former President of the American Institute of Professional Geologists. As you know, Dr. Mankin has testified before this Subcommittee and is eminently qualified in the area that I am going to address today.

The Interstate Oil Compact Commission is an organization of 35 States that are concerned with the development of oil and gas resources within their borders. The Governors of those States constitute the Board of Directors, and we are funded totally by Government funds. We do not receive any funds from the industry.

We have in recent years and are currently taking an active role in urging the initiation of a broadly expanded program of oil and gas research that includes continuing progress in existing programs, as well as a commitment to a substantially greater emphasis on oil and gas geosciences.

I am here this morning to remind you of the danger of losing a vast amount of our natural resources and the steps that we as public servants need to take to enhance and protect our national energy security and preserve our hydrocarbons. Regardless of the long-term promise of alternative fuels, for the foreseeable future, oil will continue to be a critical national energy resource. It is projected that some 20 years from now petroleum will still comprise the largest single component of primary energy demand.

If I leave one message here today, it would be that the only real energy shortage that this nation faces now or has faced in the last 15 years is a shortage of liquid transportation fuels. We have an abundance of coal; we have an abundance of nuclear energy; we have an abundance of gas, solar. Whether we use them or not is another matter. The only shortage we have is what we need to run our cars, trains, and planes.

As a nation, we have two choices as we face this shortage. We can increase domestic production to more nearly meet the demand, or we can allow imports of foreign oil to increase. Sometimes it appears that we have—for the last two years, it appears that we have commenced to choose the latter course.

I would say that imports will exceed 50 percent of total production, if not in 1989, certainly by 1990. Even the most conservative estimates put it somewhere early in the next decade.

Meanwhile, back in the oil patch—I don't have to tell you this, Mr. Chairman—things are a little tough.

Mr. HALL. I made a speech along that line just Friday.

Mr. DOWD. Yes, sir.

We plugged and abandoned more stripper wells last year. We lost 52,000 more jobs in the oil and gas and related service industries. We watched 98 more commercial banks fail in Texas, Colorado, Oklahoma, and Louisiana alone from energy loans gone sour and the related matters. Several other banks have required Federal bailouts, and others are in the wings. Meanwhile, the major oil companies are cutting their exploration, production, and research budgets on the domestic level, and more importantly, we continue to watch as our national energy security posture gradually ebbs away.

Meanwhile OPEC gets what it wants: a price which is high enough to sustain its economies and just low enough to discourage exploration and production of the highest-cost resources in the United States and elsewhere and to drive out the marginal production. And when we say that OPEC seeks to drive out the marginal production, we're talking about us.

While economic and environmentally-benign alternative fuels are being developed, they are a long way off. We have the resource in the ground, but not the understanding or the technology to produce it. Out of an estimated total original oil in place in the U.S.—493 billion barrels—we have produced 142 billion, and we have proved reserves of 27. There are 324 billion barrels of oil which we have discovered, which we do not have the knowledge at this time to get from the ground.

This is our target, and this is the message that I bring. I've brought it before, and this Committee has been responsive, this Subcommittee.

Last year, after hearing public witnesses in March and reviewing the FY 1988 budget request, this Subcommittee marked up a report that recommended a budget of $41.5 million for programs in oil, gas, and shale, an increase of $27 million above the Administration's request and about $7.5 million over the FY 1987 level as enacted.

The Subcommittee also held special hearings on the Energy Research Advisory Report, "Geoscience Research for U.S. Energy Security." The testimony delivered by a distinguished list of experts substantiated the conclusions of ERAB that existing Federal programs in oil and gas research were poorly organized and grossly underfunded.

DOE used the hearings as a forum, responded to the concerns of Congress and other interested parties by announcing the creation of an Office of Geoscience Research, reporting directly to the Assistant Secretary for Fossil Energy and a Hydrocarbon Geoscience Coordinating Committee to help plan all DOE geoscience R&D.

We see definite movement from the Department of Energy. We are, however, disappointed at the budget request that has been submitted and we don't know whether to blame Fossil Energy or OMB, but obviously it is inadequate.

The combined FY 1989 request for oil, gas and shale research still totaled just $20.9 million, a scant 3.2 percent of the FY 1989 Fossil Energy R&D request. If the $9 million requested for cooperative ventures were added, the oil, gas and shale component would still be less than 5 percent of the total Fossil Energy budget request, and some $10 million less than the budget enacted for the current fiscal year. By contrast, the Administration's FY 1989 request for Fossil Energy R&D includes $525 million for Clean Coal Technology and $104 million for other coal research. Neither the long-term dependence of this nation on oil and gas nor the stated commitment of the Administration toward expanded oil and gas geoscience research are reflected in the Administration's request.

Whether the FY 1989 request for oil and gas research reflects the desires of DOE are scraps that survived OMB's sharp knife, it represents a travesty of judgment and a failure of this Administration to understand its fundamental leadership role in national concerns, economic health and energy security.

Therefore, I urge this Subcommittee and the Full Committee on Appropriations to take the following steps.

Maintain funding authorization for existing programs at not less than $40 million per year, prioritized to emphasize light oil EOR, heavy oil EOR, unconventional gas and advanced exploratory research. Funding for tar sands and oil shale should be provided after the needs of the preceding programs have been fully met.

If these latter programs are to be given substantial funding, the existing programs should be funded at a level closer to $50 million.

Special attention should be paid to the Advanced Process Technology program, despite its non-descriptive name, this program consists largely of the cross-resource basic geoscience work that is so severely needed. A proposed cut in APT funding should be reversed. Beyond that, the program should be expanded in coordination with the next recommendation.

Authorize a new initiative in geoscience research at an incremental level of not less than $20 million per year. Although this is substantially less than the incremental $50 million recommended by ERAB, it reflects the likelihood that a strategic plan for the geoscience research program will be ready for final review by the end of FY 1988 and that several projects with potential near-term payoffs could begin early in FY 1989. Higher incremental authorizations and appropriations would be called for in future years based on the recommendations of the strategic plan.

Support the Geoscience Institute for Oil and Gas Research and Development, recently created by a consortium of 13 established universities, State geologic surveys and energy centers. Cost-shared research co-funded by the States and private industry on a 50/50 basis with DOE would help leverage Federal funds, inasmuch as all consumers of petroleum products will benefit, we recommend that Congress should allow a portion of the State's share of certain oil overcharge funds to be made available for oil and gas conservation research.

Direct the Hydrocarbon Geoscience Coordinating Committees to submit an annual progress report to Congress, detailing the DOE/DOI/USGS geoscience and extraction research activities, results and future plans. This report should include estimates of the potential recovery from known domestic oil and gas resources, both in the absence of Federal research and with the benefits of the research planned by the respective programs.

Continue the technology transfer directive. These forums will transfer the results and the technology and help identify gaps in public and private research. The Government can help fill these gaps.

The IOCC believes that these recommendations comprise the kind of program DOE would have requested were it not for OMB. We urge you to act decisively to begin to turn the tables on OPEC and restore America's ability to meet its fuel demands. We appreciated your efforts last year to begin to review and begin acting upon the recommendations of ERAB and we look forward as always to working with the Subcommittee.

Thank you, Mr. Chairman.

[The prepared statement of Mr. Dowd follows:]

TESTIMONY OF
W. TIMOTHY DOWD,
EXECUTIVE DIRECTOR
INTERSTATE OIL COMPACT COMMISSION

BEFORE THE
UNITED STATES HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE & TECHNOLOGY
SUBCOMMITTEE ON ENERGY RESEARCH & DEVELOPMENT

THE HONORABLE MARILYN LLOYD, CHAIRMAN

MARCH 29, 1988

Madam Chairman, members of the subcommittee, it is an honor to come before the subcommittee this morning to discuss the Administration's FY89 budget request for fossil energy research and development.

For more than 50 years, the objective of the Interstate Oil Compact Commission, the organization of the governors of 29 oil and gas producing states and 6 associate member states, has been to maximize the efficient recovery of America's oil and gas resources. The efforts of the IOCC are largely responsible for the stabilization of production levels in the 30's, implementation of new waterflood and pressure maintenance techniques in the 40's and 50's, and encouragement of enhanced oil recovery, production of heavy oil and tar sands, and environmental safety in the oil patch during the last 20 years.

The IOCC is currently taking an active role in urging the initiation of a broadly expanded program of oil and gas research that includes continuing progress in existing programs as well as a commitment to a substantially greater emphasis on oil and gas geosciences. So, I am here this morning not to talk about the IOCC's achievements over the past 50 years, but rather to remind you of the danger of losing a vast amount of our natural resources industry and the steps we, as public servants, need to take to enhance and protect our national energy security and preserve our hydrocarbons.

Over the years we have sounded the call that adequate supplies of oil and gas are still a vital national concern. I was astounded to hear recent survey results that showed less than 1% of Americans consider energy to be a major national problem. Madam Chairman, petroleum is important. In 1986 oil comprised more than 40% of this nation's total primary energy demand and 98 % of the nation's demand for transportation fuels.

Regardless of the long-term promise of alternative fuels, for the foreseeable future, oil will continue to be a critical national energy resource. It is projected that some 20 years from now petroleum will still comprise the largest single component of primary energy demand. The only real energy shortage this nation faces is in its supply of liquid transportation fuels.

We, as a nation, have but two choices. We can increase domestic production to more nearly meet demand or we can allow domestic production to continue its precipitous decline, thus making our nation ever more dependent on imports of foreign oil. Looking at the statistics for the past two years, it would seem that America has regrettably chosen the latter course. Last year, in testimony presented to this subcommittee, my colleagues Dr. William Fisher of the University of Texas, and Dr. Charles Mankin of the University of Oklahoma, charted -- in great detail -- the decline of our oil and gas production, and the effects of that decline on local and national economies. I am sad to report to you this morning that the situation has gotten worse.

America continues to get out of the oil business. Production has fallen 6.8% since last year at this time and 11.7% since the end of 1985. To put this in context, domestic crude oil production has fallen 18% over the past decade. Dependence on foreign oil has increased to almost 40% of demand while the domestic producing states face economic chaos. The economic cost of those imports, measured in dollars sent overseas, is manifested not only in the trade deficit, but in the foregone opportunities those dollars could create if circulated through our economy. Were it not for oil imports we could have added more than $60 billion to domestic economic activity GNP in 1987.

Instead in 1987, we plugged and abandoned more stripper wells. We lost 52,000 more jobs in oil and gas and related service industries. We watched 98 more commercial banks fail in Texas, Colorado, Oklahoma, and Louisiana alone, from energy loans gone sour. Several required federal bailouts, and others are in the wings. We watched major oil companies continue to cut their exploration and production budgets for domestic operations and make even deeper cuts in investments in research, sending their dollars overseas to more promising foreign plays. More importantly, we watched -- and continue to watch -- as our national energy security posture is gradually chipped away. I need not remind the members of this subcommittee that greater dependence on foreign oil, much of it from OPEC producers, will not hasten the day when our fleet steams out of the Persian Gulf.

But OPEC is getting what it wants: a price high enough to sustain OPEC economies and just low enough to discourage exploration and production of higher cost resources in the United States and elsewhere.

While economic and environmentally benign alternative fuels are being developed, we must continue to find ways to meet our demand for oil. We have the resource in the ground but not the understanding or technology to produce it. Out of an estimated total original oil in place in the U.S. of 493 billion barrels, we have already produced 142 billion, and we have proved reserves of about 27 billion barrels. That leaves a remaining resource of about 324 billion barrels, almost 2/3 of the original resource in place as a target for advanced technology.

The answer to reducing import dependence is increased production. And the key to increased production is highly focused research to provide the vastly improved geoscientific understanding of domestic oil and gas resources and the advanced technologies that are needed to locate and produce them. With improved reservoir characterization, geologists and engineers estimate we could produce perhaps another 90 to 100 billion barrels of our remaining oil resource through advanced enhanced recovery techniques and infill drilling in known reservoirs. That is enough to sustain current levels of production well into the twenty-first century. Even more advanced technologies and "novel concepts" could potentially produce still more, or produce it at lower cost. These estimates have a very high probability of success, but only if the research is done quickly. Otherwise marginal wells will be abandoned before the technology is available--closing economic access to the reservoirs, perhaps for all time.

Last year, after hearing public witnesses in March and reviewing the FY88 budget request, this subcommittee marked up a report that recommended a budget of $41.5 million for programs in oil, gas, and shale, an increase of $27 million above the Administration request and about $7.5 million over the FY87 level as enacted.

The subcommittee also determined that the Administration's inattention to critical research needs identified by the Energy Research Advisory Board's report "Geoscience

Research for U.S. Energy Security" merited a special hearing, that was held in July. Testimony delivered by a distinguished list of experts in petroleum research and geosciences substantiated the conclusions of the Energy Research Advisory Board that existing federal programs in oil and gas research were poorly organized and grossly under-funded. DOE, after months of silence on the ERAB report, used the hearings as a forum, responding to the concerns of Congress and other interested parties by announcing the creation of an Office of Geoscience Research reporting directly to the Assistant Secretary for Fossil Energy and a Hydrocarbon Geoscience Coordinating Committee to help plan all DOE geoscience R&D. We applaud that decision and look forward to the imminent appointment of a Director for the Office of Geoscience Research.

The subcommittee also considered ERAB's recommendation that an incremental $50 million be authorized and appropriated, in addition to existing programs, for a highly targeted program of oil and gas geosciences, derived from an analytically-based strategic research plan. The subcommittee concurred to the extent of marking up $2 million for analytically based strategic planning and was, in our view, leaning toward an incremental $20 million for geoscience research. Unfortunately, an authorization bill was not reported out. Nevertheless, we applaud this subcommittee for taking strong action. In particular we are highly appreciative of the personal interest shown by you Madam Chairman and by Mr. Chapman who chaired the Geoscience Research Hearings.

The Appropriations Committee, although in communication with the membership of this subcommittee, reported a budget somewhat less than the subcommittee's mark-up for existing programs. It recommended a budget of $36.3 million for programs in oil, gas, and shale, an increase of $22.5 million above the Administration request and about $2.3 million over the FY87 level as enacted. The final action of House and Senate conferees, though ($39.9 million -- an increase of $26 million over the budget request and about $6 million over the FY87 level) more closely approximated, in aggregate, the recommendations of ERAB for existing programs, but left substantially unfunded the recommendations for a dedicated program of geosciences.

While the Department of Energy has begun to move on several of ERAB's recommendations, including creation of an Office of Geoscience Research, much still remains to be done. I want to make it clear that it is our opinion, Secretary Herrington and Assistant Secretary Wampler have acted diligently in seeking to get the existing programs properly focused and in getting the geosciences program moving.

But, regardless of the Department's diligence and good intentions, the combined FY89 requests for oil, gas, and shale research still total just $20.9 million, a scant 3.2 percent of the FY89 Fossil Energy R&D request. If the $9 million requested for cooperative ventures were added, the oil gas and shale component would still be less than 5% of the total FE budget request, and some $10 million less than the budget enacted for the current fiscal year. By contrast, the Administration's FY89 request for fossil energy R&D includes $525 million for Clean Coal Technology R&D and $104 million for other coal research. Neither the long term dependence of this nation on oil and gas, nor the stated commitment of the Administration toward expanded oil and gas geoscience research are reflected in the Administration's request. Whether the FY89 request for oil and gas research reflects the desires of DOE or scraps that survived OMB's sharp knife, it represents a travesty of judgment and a failure of this Administration to understand its fundamental leadership role in national concerns economic health and energy security.

It's time to get back on the right track, Madam Chairman. This subcommittee has the opportunity to help make that happen. There is an alternative to massive import dependence. That alternative is expanded domestic oil production. And the key to increasing production is expanded, but targeted petroleum research. Private industry, by itself, cannot and will not carry the ball. The majors must necessarily and legitimately look out for the bottom line -- the short term interests of their shareholders -- which do not necessarily match the long-term interests of the nation. Their research -- and their corporate future -- is focused on overseas resources. The results of that research which is performed is often retained by the majors for competitive reasons.

The independents, the smaller, and often less technically sophisticated producers, have provided almost 60% of domestic oil and gas reserve additions since 1978. They are also responsible for about 40% of domestic production, much of that from stripper wells. But they lack the funds, the facilities, and the "downstream" profits to perform the fundamental research that's required.

So, the duty legitimately falls to governments, state and federal, to pick up the slack and see the work gets done to serve the public interest. To those who say "Leave it all to the industry", I say "bunk". If there were a free market worldwide in oil and gas, the free market posture of this administration's energy policy might have some scintilla of credibility. However, when prices and output levels of virtually every other oil producing country in the world are dictated by governments, a free market can hardly be said to exist. If the necessary work is getting done, ERAB would not have issued its report, and I would not be here today.

Essentially all the largest producing states have active, focused research programs, but these individually are not enough. The existing state and federal oil and gas research programs are essentially good ones. They continue to result in new extraction methods and improvements in old methods and to yield useful results that are being implemented. But due to ridiculously low federal funding levels, the programs do not go far enough. In research, we learn as much from our failures as from our successes. Many processes that were successful in laboratory bench tests have failed when applied in field scale pilots. Back at the laboratory the research was refocused to improve understanding of the process mechanisms, the results of which have included some improved process performance. But natural irregularities, or geologic heterogeneities, in the reservoirs account for much of the gap between predictable lab results and unpredictable reservoir test results. Analyses of the field test results have demonstrated that an improved understanding of reservoir heterogeneities needs to be developed before advanced production technologies can be applied predictably on a large scale. We've learned a lot about how much we don't know.

Existing research programs in oil and gas need to be maintained at a level equal to or higher than the $40 million approved by the Interior Appropriations Conferees for FY88. But, above and beyond the extraction research performed in these programs, the government needs to help spearhead a critical effort to improve the geoscientific understanding of our oil and gas resources. Madam Chairman, more than 60 organizations and individuals, representing the core of expertise in this field, concurred with the Energy Research Advisory Board's report "Geoscience Research for Energy Security" in its conclusion that until this knowledge and understanding is vastly improved, the technologies we have developed in enhanced oil recovery and advanced oil recovery will continue to yield poor results, except in the most favorable geologic and economic settings. They joined us in publicly endorsing ERAB's recommendations. I have attached the list of those concerned experts, and the position paper they endorsed, to my testimony.

There is, perhaps, no more important research project in the fossil energy area today than an improved understanding of hydrocarbon geosciences. Geosciences are the building blocks upon which all other research and development projects must be founded. Without a leap in understanding, much of our other fossil energy programs are but a shot in the dark.

I mentioned earlier that it is our opinion that DOE supports the expansion of oil and gas research in general, and concentration of fundamental oil and gas geosciences specifically. The creation of an Office of Geoscience Research within the Office of Fossil Energy and formation of a Hydrocarbon Geoscience Coordinating Committee and the increased request for Enhanced Oil Recovery are evidence of that commitment to participate. I am here today to tell this subcommittee that, while these small but welcomed steps have been taken, its time to lengthen the stride. The rates of decline and abandonments of our oil and gas fields have precluded the luxury of deferring critical new initiatives any longer.

DOE's actions, while commendable, don't go far enough. The department's simple response to Congress that there is no need for consolidation of the 17 programs of research under 3 assistant secretaries that relate to geoscience research is unacceptable, particularly when two new offices have just been created to address these matters and review the department's progress. I implore Congress not to lay down on this point. The implications to the future of our research programs are far too significant.

Therefore, I urge this subcommittee and the full Committee on Appropriations to take the following steps:

- **Maintain funding authorization for existing programs at not less than $40 million per year, prioritized to emphasize Light Oil EOR, Heavy Oil EOR, Unconventional Gas, and Advanced Exploratory Research.** Funding for tar sands and oil shale should be provided after the needs of the preceding programs have been fully met. If these latter programs are to be given substantial funding the existing programs should be funded at a level closer to $50 million.
- **Special attention should be paid to the Advanced Process Technology (APT) Program.** Despite its non-descriptive name, this program consists largely of the

cross-resource basic geoscience work that is so severely needed. The proposed cut in APT funding should be reversed; beyond that, the program should be expanded in coordination with the next recommendation.

- **Authorize a new initiative in Geoscience Research at an incremental level of not less than $20 million per year.** Although this is substantially less than the incremental $50 million recommended by the Energy Research Advisory Board, it reflects the likelihood that a strategic plan for the Geoscience Research program will be ready for final review by the end of FY88 and that several projects of potential near term pay-offs could begin early in FY89. Higher incremental authorizations and appropriations would be called for in future years based on the recommendations of the strategic plan.

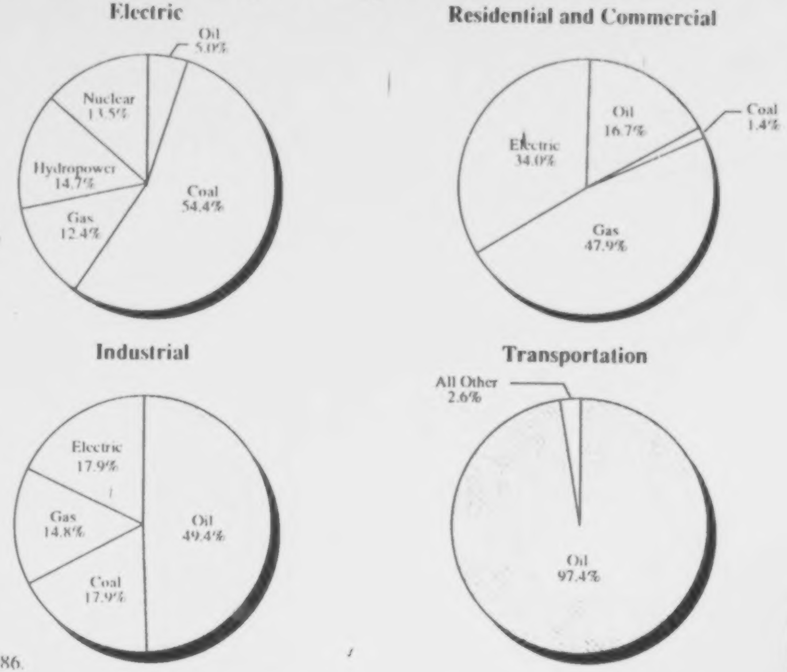
- **Support the Geosciences Institute for Oil and Gas R&D** recently created by a consortium of 13 established universities, state geologic surveys, and energy centers under the leadership of the University of Texas. Cost-shared research, co-funded by the states and private industry on a 50/50 basis with DOE, would help "leverage" federal funds. Inasmuch as all consumers of petroleum products will benefit by improved domestic production and reduced foreign imports Congress should allow a portion of the state share of oil certain overcharge funds to be made available for oil and gas conservation research.

- **Direct the Hydrocarbon Geoscience Coordinating Committee to submit an Annual Progress Report to Congress** detailing DOE/DOI/USGS geoscience and extraction research activities, results, and future plans. This report should include estimates of the potential recovery from known domestic oil and gas resources, both in the absence of federal research, and with the benefits of the research planned by the respective programs.

- **Continue Technology Transfer Directive.** These forums will transfer results/technology and help identify gaps in public and private research. Government can help fill gaps.

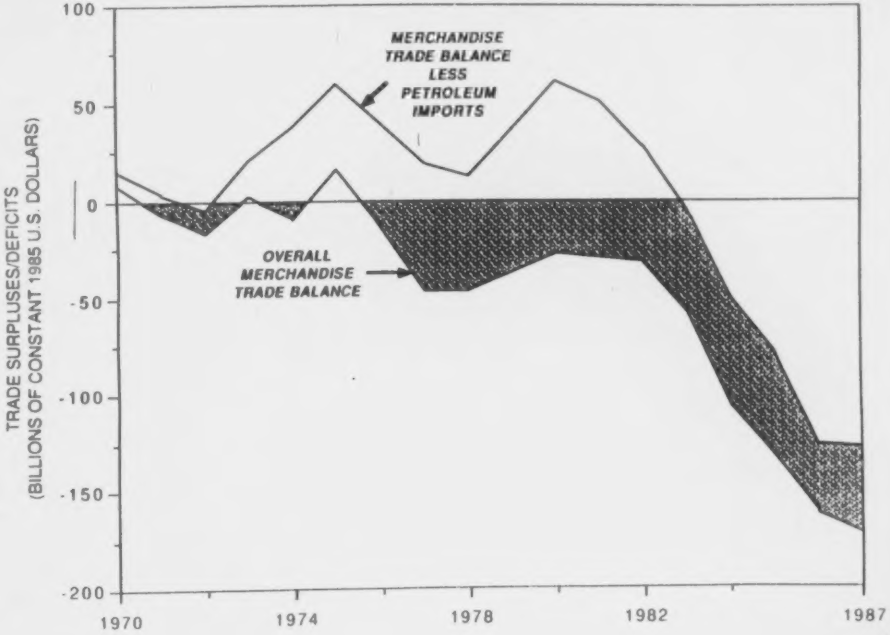
The IOCC believes that these recommendations comprise the kind of program DOE would have requested were it not for the restrictions placed on it by OMB. We urge you to act decisively to begin to turn the tables on OPEC and restore America's ability to meet its fuel demands. The IOCC appreciates your efforts last year to review, and begin acting upon, the recommendations of the Energy Research Advisory Board. We look forward to working with the subcommittee and its staff to see that our nation's oil and gas research needs are met. We hope you will join us in conveying these concerns and recommendations to your colleagues on the Appropriations Committee and to your opposite numbers in the other distinguished chamber of Congress. Thank you, Madam Chairman.

Oil is Important to Each Energy Demand Sector, But Critical to Meeting Transportation Needs



Source: API, 1986.

Oil Imports Are A Major Component Of The Trade Balance



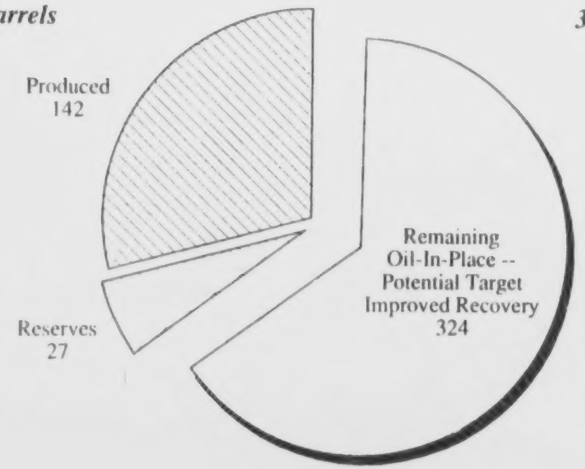
Source: U.S. Department of Commerce, 1987.

INTERSTATE OIL COMPACT COMMISSION • 1935 •

Two-Thirds of the Resource Will Remain After Conventional Production (Billions of Barrels)

Conventional
Recovery
169 Billion Barrels

Remaining
Oil-In-Place
324 Billion Barrels



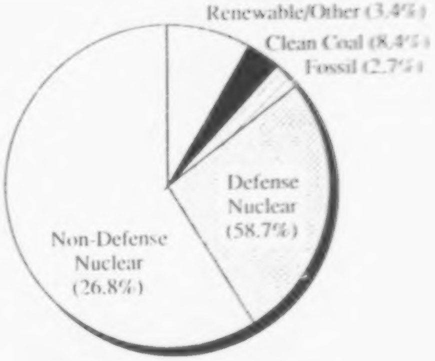
Total: 493 Billion Barrels

Source: BPO/TORIS, 1987.

INTERSTATE OIL COMPACT COMMISSION

DOE FY89 Energy R&D Funding Request

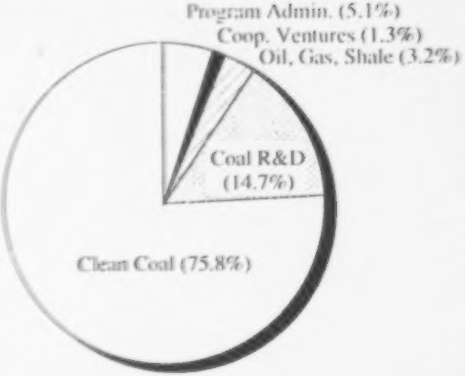
All Energy R&D



	$Millions
Defense Nuclear*	3676.6
Non Defense Nuclear*	1677.5
Other Fossil	168.0
Clean Coal	525.0
Renewable/Other	211.2

* Includes 50% of High Energy Physics

Fossil Energy R&D



	$Millions
Clean Coal	525.0
Coal R&D	101.5
Oil, Gas, Shale	21.9
Coop. Ventures	9
Program Admin.	35.5

Source: DOE February, 1987

INTERSTATE OIL COMPACT COMMISSION · 1935 ·

FISCAL YEAR 1988 OIL AND GAS RESEARCH APPROPRIATIONS AND AUTHORIZATIONS

(As Compared to FY87 Appropriations and DOE FY88 & FY89 Requests)
(Thousands of Dollars)

PROGRAM CATEGORY	FY87 Enacted	FY88 Request	HSS&T ER&D Mark-Up	FY88 Enacted	FY89 Request
PETROLEUM					
Advanced Process Technology					
Advanced Expl. Research	3,290	1,583	3,505	3,066	1,716
Arc. Offshore Research	495	417	495	417	452
Subtotal APT	**3,785**	**2,000**	**4,000**	**3,483**	**2,168**
Enhanced Oil Recovery					
Heavy Oil	2,350	2,100	2,350	3,700	3,945
Light Oil	7,211	7,200	13,600	9,850	13,038
Tar Sands	1,650	0	1,650	2,000	0
Pilot Venture Program	0	0	0	1,000	0
Subtotal EOR	**11,211**	**9,300**	**17,600**	**16,550**	**16,983**
Oil Shale	10,967	955	9,900	9,500	1,035
Subtotal Petroleum	**25,963**	**12,255**	**31,500**	**29,533**	**20,186**
GAS					
Unconventional Gas	8,009	1,600	10,000	10,400	1,734
TOTAL PETROLEUM & GAS	**33,972**	**13,855**	**41,500**	**39,933**	**21,920**
Cooperative Ventures					**9,000**

Mr. HALL. Thank you, Mr. Dowd. Mr. Ayres? You may either summarize or follow your testimony as you would like.

STATEMENT OF DR. PAUL S. AYRES, MANAGER, MATERIALS ENGINEERING LABORATORY, BABCOCK & WILCOX, LYNCHBURG, VA

Dr. AYRES. Thank you, Mr. Chairman. What I will do is illustrate the key points of my written testimony with some slides. I am Manager of the Materials Engineering Laboratory of Babcock and Wilcox, a subsidiary of McDermott Inc. I would like to thank the Subcommittee for the opportunity to speak with you this morning. The subject of my presentation is fiber reinforced ceramic composites. The objective of my testimony is to ask your enhanced support for the Office of Industrial Programs in the Conservation Branch of the Department of Energy.

Basically I will speak to the relationship of these materials to energy efficiency in the United States. I will describe the advantages of these materials. I will tell you where we are in the United States in this technology and I will illustrate my recommended program.

If we are to achieve increased energy efficiency, we can do it by increasing the temperatures of the processes and engines we deal with. Likewise, if we are to save energy, we can deal with harsher environments in those processes, save energy and increase the overall efficiency of those processes.

The kinds of examples or examples of the kinds of processes I am talking about are heat exchangers in energy production systems, gas turbines, chemical processing industry, and metal production industry.

The logic I just showed up there of increased temperature is correct. Next slide, please. The problems, however, are as you go to increase temperatures, as you go to harsher environments, you tend to run into severe material problems. The underlying problem here is that metals and alloys fail above 1,800 degrees F. even in rather benign environments such as just atmosphere.

Furthermore, the metals and alloys that do work at the higher temperatures require critical elements such as chromium and cobalt which generally speaking come from unstable, unreliable foreign sources such as Southern Africa.

There is a solution to this dilemma, however, and that is to use ceramic materials.

Next slide, please.

Again, this is a good news/bad news story with ceramic materials. Ceramic materials have high melting temperatures. They can go as high as 3,700 degrees F. as illustrated in that case by aluminum oxide. They are corrosion resistant. They are wear resistant. They can stand up to those harsh environments and they don't use critical elements. They are made instead from silicon, nitrogen, carbon, aluminum, oxygen, elements that we have in abundance in the United States.

However, again, there is a bad news side to this. There are problems with these materials. Generally, they tend to be brittle, they fail in catastrophic fashion and they are unreliable as structural materials. They are also very difficult to manufacture.

Next slide, please.

The subject of my presentation is the solution to that dilemma and that is to use fiber reinforcement in ceramic materials to overcome the brittleness problem. If you do that, you can retain the good properties of the monolithic ceramic materials and you can achieve good toughness and reliability in the ceramic material, in the composite. When I speak of a composite, I'm speaking of a complex material made of two or more constituents. The best example I can think of that we are probably all familiar with is the sporting goods, tennis rackets, golf club shafts, which are composites usually made of polymers and carbon fibers. Here we are talking about ceramic fibers and ceramic matrices.

There is still a problem with manufacturability of these materials. They are difficult to make. They are in their infancy. Today they are highly labor intensive and they must be by their nature product specific. They must be made to near-net shape. This particular piece of material here knew from the instance of its inception, from the instance of its birth, that it was going to be in the shape that I have in my hand now. It is not possible to hammer these materials into shape like you do with metals. It is not possible to even machine them. You can do it only with great difficulty. Because they are near-net shaped materials, because they are intimately related to their ultimate product application, it is highly unlikely that they will ever become commodity materials.

That is we must produce these materials ourselves if we are going to use them in the future. We will not be able to buy them as we buy steel ingots today, bring them to the United States, hammer them into shape, make them into our products.

Our competition will not sell them to us. They will use them for their own product applications.

Next slide, please.

I would like to illustrate for you briefly why this behavior is so important. I have two curves up there, the one in the lower lefthand corner illustrates what happens if you load up a piece of unreinforced silicon carbide, the load will tend to rise, the material will fail and the load will drop down precipitously as illustrated by the vertical line in the lower lefthand corner.

The silicon carbide reinforced composite in the example I have in my hand, if I load that material up, I will first of all get a much higher load before the material begins to show any signs of failure, as failure does occur, it will occur in stages. I will have some warning that the material is about to fail and in short, it starts to behave like a metal.

It tends to illustrate good toughness and good reliability. The resistance to failure is related to the area under those two curves. You can understand the tremendous difference in those materials.

Next slide, please.

I'd like to illustrate on a fine scale what this material looks like. Could you rotate that 90 degrees? This is a 500-times magnification photograph of the fracture surface of a ceramic composite. You can see the fibers sticking up from the surface. You can imagine as the crack tries to move across that material, it is interrupted by the fibers. The fibers tend to hold the material together and prevent the ultimate fracture.

Next slide.

These are examples of other pieces of material that we have manufactured. We can make these materials in realistic sizes. They are still being manufactured in the laboratory.

Next slide.

The U.S. has a good position in this technology today. We are actively working in these areas. However, it is like looking at a ten-lap race and saying we are in good shape after the first lap. Our foreign competitors in Western Europe and Japan are very actively and aggressively pursuing these areas. We need to do work in advanced fibers, we need to do work in manufacturing processing. We need to do work in testing of these materials and we also need to start scaling up and building life-size pieces of hardware.

Lastly, I would like to illustrate the program that we are recommending, the basic approach is that increased funding be given to the Office of Industrial Programs in DOE Conservation and that program be used to sponsor an effort, a combination of industry, National Laboratories and universities under overall Government coordination, to investigate the technical areas related to these materials in design, inspection, process development, fiber development and manufacturing. Specifically, we are asking that the Office of Industrial Programs be given an additional $8 million in fiscal year 1989 and that this be the initiation of a six-year program funded at the magnitude of about $90 million so that the U.S. can begin to really get started, really develop a strong base in these materials.

In summary, we believe that these materials will play a very important role in the future industrial energy efficiency of the U.S. We are working on these materials today. Our foreign competitors are pursuing them very aggressively. We need to step up our efforts.

Thank you very much.

[The prepared statement of Dr. Ayres follows:]

Views on Federal Research and Development in Support of Ceramic Composite Materials

- Importance to U. S. Energy Efficiency
- Recommended Program

Testimony before the
Subcommittee on Energy and Development
Committee on Science, Space, and Technology
U. S. House of Representatives

by

Dr. Paul S. Ayres
Manager, Materials Engineering Laboratory
Babcock & Wilcox, Lynchburg, Virginia

Babcock & Wilcox
A Subsidiary of McDermott International

March 29, 1988

Madam Chairman and Members of the Subcommittee, I am Dr. Paul Ayres, Manager of the Materials Engineering Laboratory in the Research & Development Division of Babcock & Wilcox, a McDermott Company. On behalf of the Babcock & Wilcox Company I appreciate this opportunity to express our support for increased federal participation in the development of a new class of structural materials, ceramic composites.

Specifically we ask that the Office of Industrial programs, under the Assistant Secretary of Conservation, within the U. S. Department of Energy, be provided an additional appropriation of $8 million in FY 1989 as the first step in a six-year, $91 million, committment to establish a U.S. technology base in ceramic composites to further future industrial growth.

Today, I will briefly explain why this particular materials technology is critical to the future of industrial America.

My testimony will cover: (1) a brief description of ceramic composites, (2) why they are important to U.S. energy efficiency, (3) status of the current program, and (4) a recommended program to establish U.S. leadership in this technology.

CERAMIC COMPOSITES

Ceramics are non-metallic systems that are thermally and chemically stable at temperatures exceeding 3000°F, whereas metals and alloys are limited to service temperatures below 1800°F. However, ceramics fail in a brittle fashion, which limits their structural usage, while metals exhibit ductility and toughness, distinguishing them as excellent structural materials.

Composites are a general class of materials that can be defined as the sophisticated combination of two or more distinguishable materials. Composites have more desirable properties than their individual constituents. Thus, a ceramic composite, where the ceramic material is modified by the addition of fibers that add toughness will resist brittleness that makes monolithic ceramics poor structural materials. These materials are, however, in their infancy. A comprehensive, well organized effort is required to bring these materials to maturity.

WHY CERAMIC COMPOSITES ARE IMPORTANT TO U.S. ENERGY EFFICIENCY

The efficiency of engines and electric power generating plants improves as the operating temperature is increased. Higher efficiency means less fuel consumption and cheaper energy. For example, increased efficiencies of 10-30% are possible in power generation facilities through the use of ceramic composite air heaters. Other applications with similar benefits include industrial turbines, chemical processing, and steel processing. Such advanced systems, because of higher operating temperatures which exceed the limits of metals, demand advanced materials like fiber reinforced ceramic composites. Total energy savings for these industries could exceed 0.5 quads/yr.

An additional benefit from the use of ceramic composites is reduced dependence on strategic materials. Metal alloys require strategic elements like chromium and cobalt that come mainly from unstable foreign sources. Ceramic composites utilize elements like silicon, aluminum, and carbon, which are readily available. Clearly, ceramic composites are an enabling technology that can free U.S. industry from foreign dependence.

The U.S. is not alone in recognizing the importance of this technology. To date the Japanese have not launched a concerted effort in ceramic composites, choosing instead to focus on monolithic ceramics. Today the U.S. is ahead. However, if we do not aggressively pursue this technology and they do, the results will be very severe for U.S. industry. Since composites are generally tailored to a specific application (that is they go from raw material to processed shape in a continuous step), they will not be available as commodity materials in the world market as are steel ingots. Without the development of ceramic composite processing capability, high efficiency industrial systems will not develop. The choice is not "make or buy", but "make or die".

PROGRAM STATUS

Babcock & Wilcox has been involved in the development of fiber reinforced ceramic composites on a DOE sponsored project for the past three years. The project has generated information on the stability of ceramic fiber at elevated temperatures, the effect of processing variables on fiber integrity, and the appropriate process parameters to optimize material properties.

We are making tubular shapes and evaluating these materials at temperatures to 2000°F. The critical parameter is non-brittle behavior, which we have demonstrated at these temperatures.

Over the next two years we will be scaling up our fabrication process to make larger components and performing field tests on these components in various industrial applications.

Ceramic composites technology is still in the very early stages of development. Twenty-five years ago resin matrix composites were in a similar position, but with sustained support from federal agencies, these materials are now routinely utilized in aircraft, missiles, automobiles, and sporting goods.

The development of ceramic composites should parallel the heat exchange system development described in the following section.

THE RECOMMENDED PROGRAM

Presently the Advanced Heat Exchanger Program, within the DOE Office of Industrial Programs, has an ongoing effort to develop a High Pressure Heat Exchange System based on advanced ceramic composites. This program does not, however, have adequate funding to develop ceramic composite technology at the rapid pace needed to keep U.S. technology ahead of foreign competition. What is needed is an addition to the program, based on a six-year plan that will couple the resources of our universities, national laboratories, and industry to establish a firm base of ceramic composite technology in the U.S.

The recommended program is a multi-million dollar effort involving multiple firms. This program will include material and process development with support from disciplines in fracture mechanics, non-destructive testing and interfacial micro-analysis. The material and process development would address major issues such as ceramic fiber development, fiber-matrix interface control, and matrix deposition. The combination of industry, national laboratories, and universities will provide a solid base to promote industrial usage. For your consideration, I have attached to my testimony details of the subject program.

SUMMARY

To summarize, B&W believes that ceramic composites will be the next major advance in structural materials. At maturity this will enable the design and construction of advanced engines, power generation equipment, and chemical processes operating at temperatures beyond the reach of today's materials. The higher operating temperatures of these advanced systems will in turn mean higher efficiencies for these industries and give them a real advantage in world competition.

The development of ceramic composites is a major technical challenge. This challenge requires and deserves the unified, concerted efforts of U.S. industry, national laboratories, and universities. Furthermore, the Federal Government should co-fund this effort and serve as its integrator. We believe that the proposed program can succeed and we request your support for this program.

Thank you for your attention.

ATTACHMENT

The following information supports the testimony of Dr. Paul Ayres of Babcock & Wilcox. Included are suggestions on how the proposed program might be structured; industrial applications for the resultant products; and a flow-chart showing the proposed structure of DOE-OIP's program on high pressure heat exchanger system development. The current DOE program, though under-funded, contains the type of team-work required to successfully complete materials development.

RECOMMENDED PROGRAM STRUCTURE

The intent of this recommendation is to outline the basic technology needs for the development of fiber reinforced ceramic composites. There are two major thrusts to the development of ceramic composites: design studies and process development.

DESIGN STUDIES

This work encompasses three major fields of study to ensure reproducible, well engineered structures. These three fields are non-destructive testing, microanalysis, and composite fracture mechanics. This activity would involve the cooperation of National Laboratories such as INEL and ORNL, Universities such as VPI and Drexel, and industrial partners.

Non-destructive testing:

- development and implementation of acoustic proof-testing and methodology.

- combined program such as current B&W-INEL program on monolithic ceramics.

Micro-analysis:

- University led programs to characterize the fiber-matrix interfacial region of the composites. This area controls the ability of the ceramic composites to maintain a non-brittle fracture mode.

- Requires applications of equipment like scanning electron microscopes, auger microprobes, and other apparatus to resolve interfacial chemistry and structure.

- Suggested format are three university teams, each with industrial and national laboratory support, each at approximately $150K/yr level.

Fracture Mechanics:

- This joint effort would address the failure mechanism and design requirements associated with ceramic composites.

- Again, three teams should provide adequate growth in this discipline.

Process Development:

The goal is to push U.S. industry processing capabilities.

- First year activities will provide up to ten companies with support to identify possible limitations and boundary conditions of their proposed process.

- The remaining years would provide up to five companies the funding (@3MM/yr) to address the critical aspects of their process and target for specific industrial applications.

- Beyond six years industrial applications and spin-offs should help maintain the drive to improve ceramic composites.

This total effort would establish several companies with the basis for commercializing a new material. The funding of support teams with specific application goals will secure the growth of this technology.

INDUSTRIAL APPLICATIONS IN U.S. INDUSTRY FOR CERAMIC COMPOSITES

- High Pressure Heat Exchanger Applications

  Needs:

  - Projected applications in power generation, chemical processing, and heat recovery
  - 1987 assessment of national panel of experts, estimated: One-half quad annual energy savings and $2.1 billion in annual cost savings for U.S. industry

  Status:

  - Development plan proposed but underfunded

- Large Stationary Turbine Applications

  Need:

  - Projected applications to scroll, turbine wheel, other components
  - Projected plant efficiency gain >4%

  Status

  - Development plan needed

- Steel Casting and Rolling

  Need:

  - Projected applications in continuous casting include slide gate values and nozzles; non-magnetic components for electromagnetic casting; and projected applications in small rolling (primary work roll).
  - Benefits are precision shape control, increasing product uniformity, overall quality, and reducing scrap.

  Status:

  - Development plan for rolling needed, development plan for casting being formulated.

- Other Applications

  Need:

  - Projected applications in pulp and paper (smelt value) and other industries

  Status:

  - Assessment needed
  - Although projected to include numerous mundane applications, is potentially larger than previous 3 applications identified above.

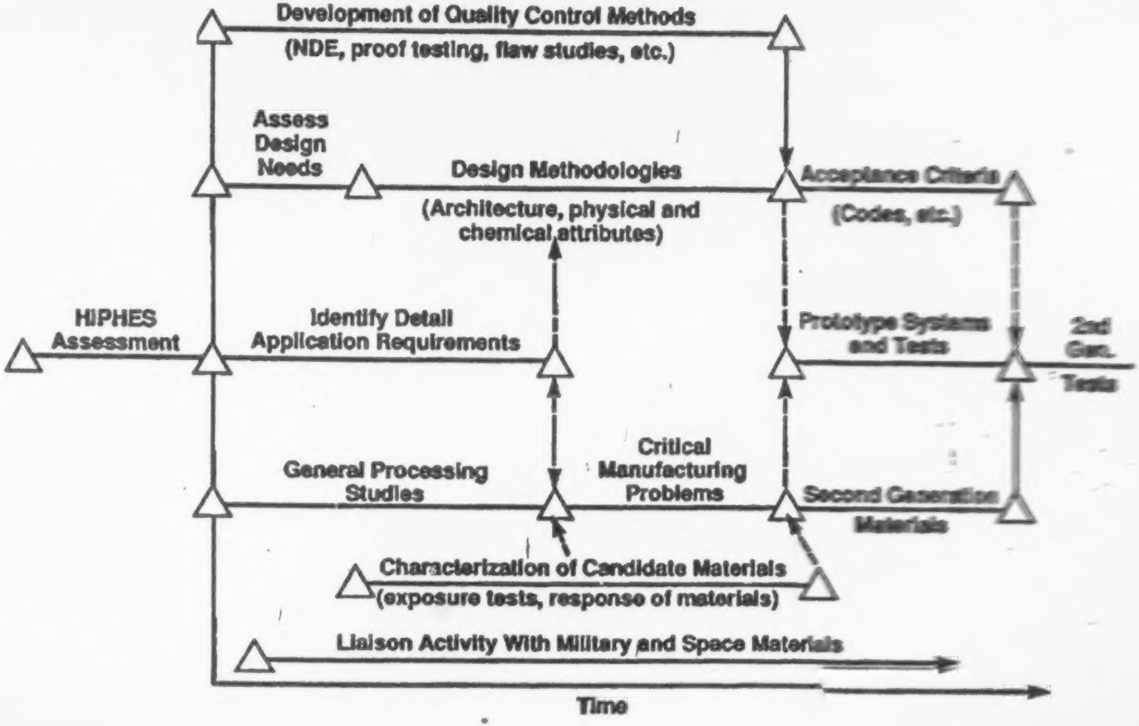
TABLE I
FIBER REINFORCED CERAMIC COMPOSITES PROGRAM
PROPOSED SCHEDULE AND BUDGET

SUBJECT	1989	1990	1991	1992	1993	1994
DESIGN NON-DESTRUCTIVE TESTING	$750K	$750K	$750K	$750K	$500K	$500K
INTERFACIAL MICROANALYSIS	$500K	$500K	$500K	$500K		
COMPOSITE FRACTURE MECHANICS	$750K	$750K	$750K	$750K	$500K	$500K
PROCESS STUDIES	SCOPE OF PROCESS $6M	DEVELOPMENT OF CRITICAL PROCESS ASPECTS $15M	$15M	$15M	$15M	$15M
TOTAL FUNDING	$8M	$17M	$17M	$17M	$16M	$16M

The following chart describes the program on high pressure heat exchange systems currently funded under the Advanced Heat Exchangers Program in the Office of Industrial Programs—a section within the Department of Energy. This proposed approach addresses the critical needs to advance ceramic composites but lacks the funding to properly posture U.S. Industry in developing ceramic composites.

Advanced Heat Exchangers Program

RECOMMENDED HiPHES DEVELOPMENT PROGRAM



HiPHES Assessment

Development of Quality Control Methods
(NDE, proof testing, flaw studies, etc.)

Assess Design Needs

Design Methodologies
(Architecture, physical and chemical attributes)

Acceptance Criteria
(Codes, etc.)

Identify Detail Application Requirements

Prototype Systems and Tests

2nd Gen. Tests

General Processing Studies

Critical Manufacturing Problems

Second Generation Materials

Characterization of Candidate Materials
(exposure tests, response of materials)

Liaison Activity With Military and Space Materials

Time

Mr. Hall. Thank you, Dr. Ayres. Dr. Hartnett?

STATEMENT OF DR. JAMES P. HARTNETT, PROFESSOR OF ENGINEERING AND DIRECTOR, ENERGY RESOURCES CENTER, UNIVERSITY OF ILLINOIS AT CHICAGO, AND SECRETARY, MIDWEST UNIVERSITIES ENERGY CONSORTIUM INC., CHICAGO, IL

Dr. Hartnett. Thank you, Mr. Chairman. My name is James Hartnett. I'm Professor of Engineering and Director of the Energy Resources Center at the University of Illinois, in Chicago.

During the past 16 years, I've also served as a member of the Illinois Energy Resources Commission, which acts as an Advisory *Board to the Illinois General Assembly on matters of energy.*

But, I come to you today as the spokesman for the Midwest University's Energy Consortium, representing the 20 major research institutions in the Big 10 States of Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio, and Wisconsin.

We in the Midwest share the concern of all Americans about our continuing ability to compete in the world marketplace. We are convinced that we need a strong research base to provide the new ideas that will allow the United States to stay at the forefront of high technology.

Against this background, I would like to call the Committee's attention to an area of engineering research which is currently under funded, an area which has the potential for substantial return on investment in both the short and long term.

I refer to multiphase flow research. Multiphase flow involves such systems in which more than one phase is present, such as steam and water, coal and air. Such flows are more complex than those in which a single phase alone is present.

To give a few examples, multiphase systems are encountered throughout the petroleum extraction and processing industry, the coal industry, the nuclear power industry, the steel industry, and the automobile industry.

Fluidized-bed combustion of coal, coal slurry pipelines involve multiphase flow. And, we could build bigger, better, and more efficient systems if we had more knowledge about these flows.

In brief, an improved understanding of multiphase flow would allow many major national industries to improve their systems design, increase their overall efficiencies, improve safety, and thus, provide a competitive edge which is so critical to the future of American Industry.

An increased engineering research effort in multiphase flow would fall within the provinces of the DOE Office of Basic Energy Sciences. Approximately $3 million per year would be required to support an adequate regional program.

For this to occur, it is critical that the division of engineering budget of the Office of Basic Energy Sciences be increased.

At the present time, the DOE has allocated only $15 million for basic engineering research, which represents four percent of the total basic energy sciences budget of $334 million.

The current move to improve America's competitive position in the international marketplace is essentially an engineering problem; consequently, it becomes critical that support for engineering research be raised accordingly.

In terms of the multiphase flow program, Argonne National Laboratory and the Midwest University's Energy Consortium, have a comprehensive proposal in place, which has undergone peer review. It could be initiated without delay if funding were made available.

The second point I'd like to make today is that the research effort should involve the university system, the National Laboratories, and industry. This is consistent with the findings of the White House Science Council, and with the recommendations of the Energy Research Advisory Board.

Both of these prestigious groups concluded that the development of close collaboration and research between these three partners is a high national priority.

In response to this mandate, the Midwest University's Energy Consortium and Argonne National Laboratory, along with regional industry, have been working to develop a collaborative research program in this important area.

Such collaboration involves students, post doctoral fellows, takes full advantage of shared facilities, including laboratory equipment, supercomputers, and it obviously offers a real potential for a maximum return on invested research dollars.

There are a few specific activities which I'd like to mention because they do reflect an active industrial component in the university/national laboratory/industry cooperative formula.

First of all, MUEC and Argonne National Laboratory, with the cooperation of Amoco Oil Company, are sponsoring a series of short courses in multiphase flow designed especially for practicing engineers.

The program is unique in that it provides engineers working in the field with access to university and National Laboratory expertise and sets a model for future cooperation.

Two, as a part of the Midwest multiphase flow initiative, an industry advisory council is being formed to increase the industrial role in participation in the collaborative research effort.

Three, a planning committee involving representatives from industry, the National Labs, Government, and universities, has scheduled a series of workshops to prepare a national plan for collaborative engineering research.

We are aware of related initiatives in other regions of the country to increase support for engineering research. For example, INEL, MIT, Brookhaven, Sandia, Oak Ridge, all have expressed interest in moving into cooperative engineering research.

We are meeting on a regular basis with some of these groups to achieve a coordinated approach to this nationally important area.

In conclusion, on behalf of the Midwest University's Energy Consortium, I'm asking for your assistance in providing additional engineering funding for an important research area, multiphase flow.

I'm also seeking your support in the development of new research partnerships between universities, National Laboratories, and American industry.

Thank you very much, Mr. Chairman.

[The prepared statement of Dr. Hartnett follows:]

Testimony

Submitted by:

James P. Hartnett
Secretary
Midwest Universities Energy Consortium Inc.

P.O. Box 5478
Chicago, IL 60680
312/996-4490

House Committee on Science, Space and Technology
Energy Research and Development Subcommittee

March 25, 1988

My name is James P. Hartnett. I am Professor of Engineering and Director of the Energy Resources Center at the University of Illinois at Chicago. During the past 16 years I have also served as a member of the legislatively appointed Illinois Energy Commission (currently called the Citizens Energy Council) which acts as an advisory board to the Illinois General Assembly on matters of energy.

But I offer this testimony as the spokesman for the Midwest Universities Energy Consortium, representing the 20 major research institutions in the Big Ten States of Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio and Wisconsin (the names and locations of the member institutions are shown on the attached figure).

We in the Midwest share the concern of all Americans about our continuing ability to compete in the world marketplace. We are convinced that we need a strong research base to provide the new ideas that will allow the United States to keep at the forefront of high technology. Against the background, I would like to call to the committee's attention an area of engineering research which is currently underfunded; an area which has the potential for a substantial return on investment in both the short and long-term. I refer to multiphase flow research.

Multiphase flow involves systems in which more than one phase is present, such as steam (gaseous phase) and water (liquid phase); coal particles (solid phase) and air (gaseous phase). Such flows are much more complex than those in which a single phase alone is present. To give a few examples, multiphase systems are encountered throughout the petroleum extraction and processing industry, the coal industry, the nuclear power industry, the steel industry and the automobile industry. Fluidized bed combustion of coal or coal slurry pipelines involve multiphase flow and we could build bigger, better and more efficient systems if we had more knowledge about these flows. In brief, an improved understanding of multiphase flow would allow many major national industries to improve their system designs, increase their overall efficiencies, improve their safety and thus provide a competitive edge which is so critical to the future of American industry.

An increased engineering research effort in multiphase flow (liquid-gas systems) would fall within the province of the DOE Office of Basic Energy Sciences (BES). Approximately $3 million would be required to support an adequate research program on a regional basis. For this to occur, however, it is critical that the Division of Engineering budget of the Office of Basic Energy Sciences be increased. At present the DOE has allocated only $15 million for basic engineering research which represents approximately 4% of the total Basic Energy Sciences budget of $344 million. The current move to improve America's competitive position in the international marketplace is essentially an "engineering" problem; consequently it becomes critical that support for engineering research be raised accordingly.

In terms of multiphase flow research, Argonne National Laboratory and the Midwest Universities Energy Consortium have a comprehensive proposal in place which has already undergone peer review. It could be initiated without delay if funding is made available.

My second point is that the research effort should involve the university system, the national laboratories and industry. This is consistent with the findings of a White House Science Council Report and with the recommendations of the DOE Energy Research Advisory Board. Both of these prestigious study groups concluded that the development of close collaboration in research between universities, national laboratories and industry is a high national priority. In response to this mandate, the Midwest Universities Energy Consortium and Argonne National Laboratory, along with regional industry, have been working to develop a collaborative research program in the important area of multiphase flow research. Such collaboration involving students and post doctoral fellows, taking full advantage of shared facilities including laboratory equipment and supercomputers obviously offers a real potential for maximum return on invested research dollars.

There are several specific activities which I'd like to mention because they reflect an active industrial component in the university, national laboratory, industry cooperative formula:

1) First of all MUEC and Argonne National Laboratory with the cooperation of Amoco Oil Company are sponsoring a series of short courses in multiphase flow designed specially for practicing engineers. The program is unique in that it provides engineers working

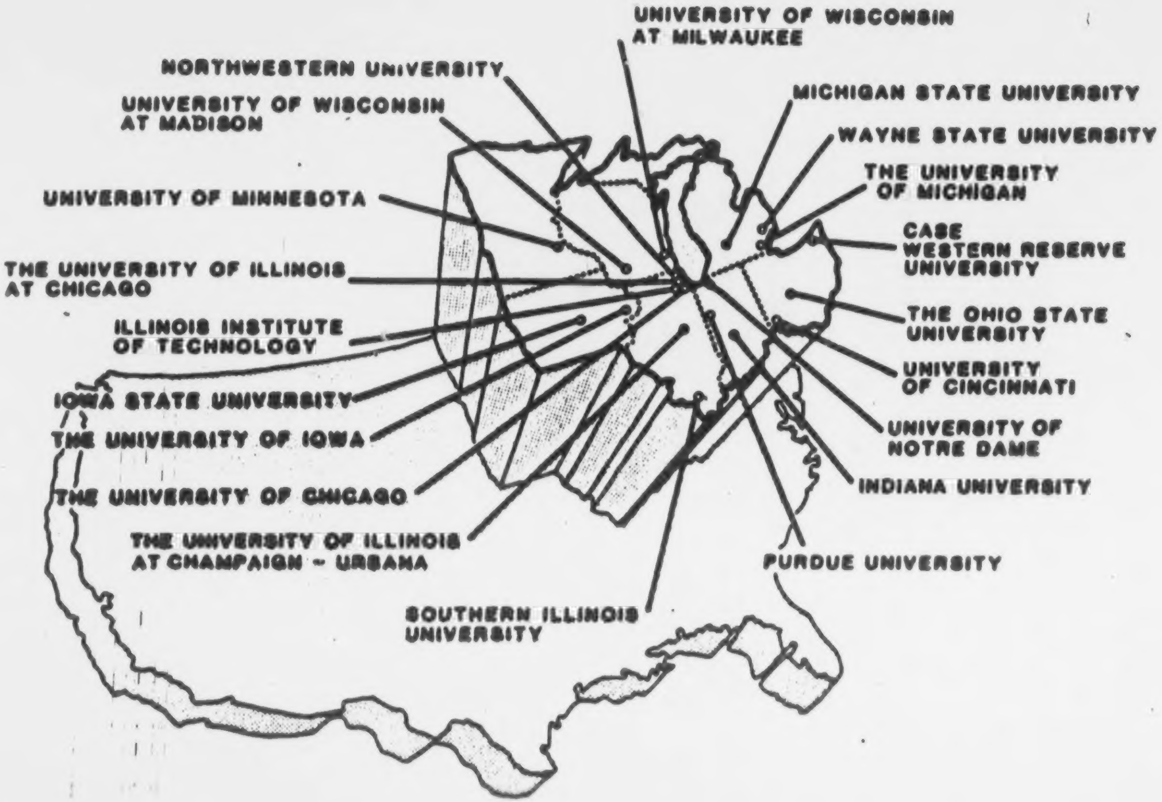
in the field with access to university and national laboratory expertise and sets a model for future cooperation.

2) As part of the midwest multiphase flow initiative an industry advisory council is being formed to increase the industrial role and participation in the collaborative research process.

3) A planning committee involving representatives from industry, the national laboratories, government, and universities has scheduled a series of workshops to prepare a national plan for collaborative research process.

We are aware of related initiatives in other regions of the country to increase support for engineering research. We are meeting on a regular basis with some of these groups to achieve a coordinated approach to this nationally important area.

In conclusion, on behalf of the Midwest Universities Energy Consortium, I am asking for your assistance in providing additional engineering research funding for an important research area, multiphase flow. I am also seeking your support in the development of new research partnership between universities, national laboratories and American industry.


UNIVERSITY OF WISCONSIN AT MILWAUKEE
NORTHWESTERN UNIVERSITY
UNIVERSITY OF WISCONSIN AT MADISON
MICHIGAN STATE UNIVERSITY
WAYNE STATE UNIVERSITY
THE UNIVERSITY OF MICHIGAN
UNIVERSITY OF MINNESOTA
CASE WESTERN RESERVE UNIVERSITY
THE UNIVERSITY OF ILLINOIS AT CHICAGO
THE OHIO STATE UNIVERSITY
ILLINOIS INSTITUTE OF TECHNOLOGY
UNIVERSITY OF CINCINNATI
IOWA STATE UNIVERSITY
THE UNIVERSITY OF IOWA
UNIVERSITY OF NOTRE DAME
THE UNIVERSITY OF CHICAGO
INDIANA UNIVERSITY
THE UNIVERSITY OF ILLINOIS AT CHAMPAIGN - URBANA
PURDUE UNIVERSITY
SOUTHERN ILLINOIS UNIVERSITY

MEMBERSHIP OF THE MIDWEST UNIVERSITIES ENERGY CONSORTIUM INC.

PANEL 2 DISCUSSION

Mr. **Hall**. Thank you, Professor Hartnett. I guess, Dr. Ayres, I want to start with you and ask you a thing or so about your ceramic composites.

How many domestic companies do we have pursuing that, or doing research on that? Do you know?

Dr. **Ayres**. I'm not absolutely certain, but I would say that, if you're talking about industrial firms——

Mr. **Hall**. Yes.

Dr. **Ayres**. There's probably about 15 or so, 20 in the United States that are actively pursuing this area, in any magnitude.

Mr. **Hall**. Any real leaders in that group?

Dr. **Ayres**. There is certainly a number of them. I would like to number my own laboratory amongst those.

Mr. **Hall**. What is your laboratory?

Dr. **Ayres**. The Research and Development Division of Babcock & Wilcox Company, in Lynchburg, Virginia. Ohio is very active in this area; there are also people who are working in the area of fibers, Dupont for example, is working very actively in fibers.

In fact, we are teaming with Dupont to use their new fibers, combining their new fibers with our ceramic composite manufacturing techniques.

Mr. **Hall**. At one time, didn't the industry look to titanium for heat shield? What's the melting point of titanium? Substantially less than——

Dr. **Ayres**. I'm not sure what the melting temperature of titanium is, sir, off hand. The problem with titanium, however, is if you try to use it at high temperatures, it will react with the oxygen and the moisture in the air very quickly at high temperatures to form an unstable corrosion product, which will limit its usefulness to a lower temperature.

Mr. **Hall**. This seems like a real breakthrough to me. I think the fiber reinforcement, don't they use that same material now for construction of helicopters?

Dr. **Ayres**. Yes, those are used, the materials you're referring to, are polymer matrix, composites, which I don't know if you're a golfer or tennis player but, if you have a composite golf club shaft or tennis racket, it's essentially the same class of materials.

We're talking about applying that same materials philosophy, which is to combine several materials to get benefits that none of those materials have.

In particular, though, we're talking about ceramic fibers and ceramic composites, so we get the good high-temperature properties that are inherent in ceramics, without the brittleness. That's really the problem that is holding ceramics back, and if you were visiting my laboratory where I have tile floors, this is a piece of silicon carbide which was used to generate the data that I showed you on the view graph.

Typically, what I do is throw this on the tile floor and illustrate that this piece of material will bounce, it will not break because of the fiber reinforcement.

If I took an ordinary piece of silicon carbide and threw it on the floor, it would shatter. And really, that is the difference. I need, as a materials engineer, I know I need that kind of toughness and resiliency in the material, if I'm going to build power plants out of it, and chemical processing plants.

In short, I can't afford to have the material fail in a brittle fashion during the life of the component.

Mr. **Hall**. Do you propose the $91 million program over a six-year time frame to pursue that and the ceramic composites?

Dr. **Ayres**. Fiber-reinforced ceramic composites, yes, sir.

Mr. **Hall**. If your program should be adopted, where will we be comparatively in the development with regard to maybe our nearest international competitors at the end of that six-year period?

Dr. **Ayres**. Hopefully, if we use the money prudently and efficiently, we will be at the leadership position in that race. There are other programs going on. This is not the only one; there are programs going on in the defense area, but if you look at all of those, they're really very small programs that are addressing this technology.

We participate in some of the defense programs so I know the magnitude of those programs. They are really relatively small programs.

Mr. **Hall**. You probably start with Japan, but what are the other countries, who are our competitors?

Dr. **Ayres**. Certainly Japan is one of our competitors, West Germany, France, Sweden, are all actively pursuing this area. Great Britain was pursuing a while back; they've kind of backed off a little bit, but Germany and France and Sweden and Western Europe are very adequate.

Mr. **Hall**. I thank you, Dr. Ayres.

Dr. **Ayres**. I'd like to thank the Subcommittee for having the opportunity to speak with you. Thank you very much.

Mr. **Hall**. Let me say to each of the three of you, not to gauge the interest of the Committee, the Subcommittee, nor the Congress by the lack of attendance here. We do take all of your testimony; it is reduced, and studied, and highlighted by staff, and we get the benefit of it, and we're very grateful to you for the great amount of time, obviously, that you all have put in, and the time you've given us today.

I recognize Mr. Morrison.

Mr. **Morrison**. Thank you, Mr. Chairman. We appreciate the testimony. Mr. Dowd, I've been very impressed as one not from an oil-producing area with the story that you have shared with this Subcommittee through the years and appreciate your kind words on our efforts. I'm sorry that the views are not universal.

Could we really supply all of our domestic needs if price wasn't an object on oil products?

Mr. **Dowd**. Let me ask—I came for the easy questions, how about Charlie for the hard.

Mr. **Morrison**. We've heard from him before, make sure we get your name for the records.

Dr. **Mankin**. Yes, I'm Charles Mankin, Director of the Oklahoma Geological Survey.

I would think it would be very difficult for the United States to achieve energy independence in terms of petroleum supply.

We are clearly a marginal-producing country. The average production has been illustrated to be on the order of 14 to 15 barrels a day per well in the United States.

We, under the best of conditions, I think it would be probably the greatest success we could have would be to arrest our decline in production.

We have, in the past, as a result of the effort through the so called "energy crisis" from 1973, an increased drilling effort, in fact, resulted in about a three-percent increase in domestic production. But, that's probably about the level we could anticipate through a very effective program of selected in-fill drilling to address the question of unswept mobile oil, and also through a program of enhanced oil recovery.

The point of this is not so much to achieve energy independence in the sense of supplying all of our petroleum needs, but it is an issue of being able to supply an adequate level so that we can be prevented from being held hostage from foreign sources of supply.

Mr. MORRISON. What sort of a price would be the optimum from the point of view of expanded U.S. production, using maybe some new technologies?

Mr. DOWD. Well, it's an infinite number in that $100 a barrel is going to produce more oil than $90 a barrel. I use those recognizing that they are both unrealistic at this time.

We recently did a study for the State of Oklahoma that showed that at something in the neighborhood of $24, $25 with State tax incentives, and a normal evolution in the knowledge, we could perhaps double reserves in that State.

The legislature took that information and granted those incentives by legislation, and now it remains for us to do two things; and one of them is get the price to $24, where we can test whether the study was right; and the other one is deliver the product.

I'm optimistic that if we could do the first, we could do the second. I think what I'm really saying is that it's not going to take more than much more than a modest increase in price, and the proper climate and the proper research partnership, if you will, and I think of it as a tripartite partnership between the States as the natural guardian of the resources, the industry which has it's role to play, and the Federal Government as the coordinator and to a certain extent, to a limited extent, a funding mechanism.

Mr. MORRISON. Your comments just now just underscored something that was in your testimony and that is that OPEC is playing this just right.

Mr. DOWD. Absolutely.

Mr. MORRISON. Just high enough to guarantee dramatic levels of income for them, and just low enough to make sure that we can't afford to play their game. I wonder what sort of an oil import fee, since our Chairman can't ask this I'll do it, what sort of an oil import fee it would take to maybe not go so high, Mr. Chairman, that we upset the tax increase folks, but high enough that if we applied it all to oil research recovery, or recovery research, that we could come closer to at least not being blackmailed again, sometime in the future.

Mr. DOWD. If you were to allocate something like 50 cents a barrel of domestic production, or 50 cents a barrel of imports; let's see, 50 cents a barrel of imports would produce \$2½ million a day, which is \$17½ million, \$850 million in a year; don't hold me to it, am I under oath, quick math. And, we are here talking in terms of hopefully \$21/\$25 million to go into research.

Mr. **Morrison**. So the axle figure to go dramatically above the level that you're talking about would be almost infinitesimal.

Mr. **Dowd**. As I pointed out in my testimony, the amount of the DOE budget that's allocated to the only energy source that we have assured.

Mr. **Morrison**. Mr. Chairman, I want to mention this, only because I'd like to have it on the record, and that is I really worry about this part of our responsibility on this Subcommittee, that is a new responsibility for us, and I guess I really take it seriously, that is we're marching down a path that I think gets this country in deep and serious trouble and even though you and I both vote against tax increases generally, this is one that I think if it were dedicated to research, the American public would buy so quickly and that we should consider an oil import fee that would go back into not allowing us to be under the foreign gun again.

Mr. **Hall**. Well, I really, of course, thank the gentleman for the friendly question and Mr. Dowd for his good answer.

I think we realize, from the energy States, that we have to put something with an oil import fee if we're ever to receive it, and it has to be something for people in the North and East, and with the heating oil problems, and we have to have an answer to those who would tell Members of Congress who have to vote for or against that, those who vote for it have some explanation as to why maybe their gasoline price goes up, and some answer for the real problems that they have in the North and East; for some of the poorest people there who use heating oil.

So, I think there are a lot of thrusts in that direction. The Lyceum Group met, I think, three days last week in my State just to study simply the national defense impact on this country because of imported oil.

I gave them a very biased speech on it and there were as many as five, ten or twelve percent that wanted to succeed at the end of my speech. But, they reconsidered.

At any rate, I'm not among those who say, "Let the Yankees freeze in the dark." It's a national problem. Energy is a national thrust and we have to have an answer for it.

Just like railroads, I vote for Amtrak. The dang thing just whistles three times a week in my District, but it leaves about every 40 minutes going from here to New York; but it's a national asset that we have to have. So, I thank the gentleman.

I think other Members may have some questions to propound to you gentlemen, and I'll make it available to them to do so, and we'll send them to you, and we do thank you for your time. We will be adjourned.

[Whereupon, at 12:25 p.m., the Subcommittee recessed, to reconvene at the call of the Chair.]

1989 DEPARTMENT OF ENERGY AUTHORIZATION

WEDNESDAY, MARCH 30, 1988

House of Representatives,
Committee on Science, Space, and Technology,
Subcommittee on Energy Research and Development,
Washington, DC.

The Subcommittee met, pursuant to notice, at 9:32 a.m., in room 2318, Rayburn House Office Building, Hon. Marilyn Lloyd (Chairman of the Subcommittee presiding.

Mrs. Lloyd. The Subcommittee will come to order.

Good morning, ladies and gentlemen.

Before we proceed, I ask unanimous consent that today's hearings be recorded by electronic device. If there is no objection, so ordered.

Today's witnesses will be presenting to the Subcommittee testimony on the Department of Energy's fiscal year 1989 budget request for General Science and Research Programs. These are the programs that include major facility operations in high energy physics and nuclear physics. This budget category also includes the Superconducting Super Collider which, as all of you know, has engendered a great deal of discussion here on the Hill.

I think it is very important for us to recognize that beyond the singular issue of whether or not we should go forward with the SSC, there is a great deal of good science being conducted across the country in high energy physics and nuclear physics. In fact, exclusive of the Superconducting Super Collider, the Department's budget includes more than $830 million to cover both the programmatic activities and facility operations in these two disciplines.

Clearly, this nation still remains the world's leader in the exploration of the most fundamental aspects of matter, and today's witnesses will help us to understand more clearly what this program has accomplished over the past year and what it expects to accomplish in fiscal year 1989.

We will begin today's hearings with Dr. James Decker, who is Acting Director of the Department of Energy's Office of Energy Research, and he will be followed by the Chairman of the High Energy Physics Advisory Panel and the Nuclear Science Advisory Committee. This panel will be followed by witnesses representing the major facilities in high energy physics at the Stanford Linear Accelerator Center and Fermilab.

In nuclear physics, the major programs and facilities will be described by representatives from the Continuous Electron Beam Accelerator Facility, Brookhaven National Laboratory, the Bates Laboratory and the Los Alamos Meson Physics Facility.

We will be receiving testimony on a project that this Committee believes must begin construction in fiscal 1989, that is, the Relativistic Heavy Ion Collider at the Brookhaven National Laboratory. I have been very concerned that the Department has for the second year delayed the beginning of construction activities for this facility which is critical to the United States' leadership in heavy ion research.

I am also concerned that the fiscal year 1989 request on the CEBAF construction will not be sufficient to assure the timely implementation of this facility without incurring further significant cost accelerations.

I would now like to call on my colleague, the Ranking Republican of the Subcommittee, Congressman Sid Morrison, for his opening remarks.

Mr. MORRISON. Thank you, Madam Chairman. I am delighted to be here this morning and to greet our witnesses as we look in the area of high energy physics and nuclear physics. These areas have come under the Subcommittee's jurisdiction since last year, and Dr. Trivelpiece did an excellent job of guiding us into this new arena. As much as we miss him, we certainly welcome Dr. Decker and look forward to his testimony and leadership.

As I preview the DOE budget request in High Energy Physics and Nuclear Physics for fiscal year 1989, I notice that the major increase in funding for both is in the construction of new facilities. The major new initiative is the Superconducting Super Collider, and although my State did not become one of the seven finalists, I must commend the DOE for having completed a difficult first step toward an important mission which was initiated from this subcommittee.

Keeping the construction of the Continuous Electron Beam Accelerator Facility, or CEBAF, on schedule is also an important task because when this facility becomes operational in fiscal 1994, it will be a unique nurturing ground for world class research in nuclear physics.

The Department is facing a challenge in the High Energy and Nuclear Physics programs because it is not easy to keep a balance between the construction of new facilities and operation of existing facilities. We need to keep in perspective that some of these facilities, such as the Tevatron at Fermilab and the Stanford Linear Collider and the facilities at Brookhaven, Berkeley and Los Alamos are also world class. I think we need to make the best of them and try to enhance their use to higher than the current 50 percent level.

I look forward to gaining some insight into these areas from our witnesses today. Madam Chairman, I thank you.

Mrs. LLOYD. Thank you very much, Mr. Morrison.

Will you please proceed, Dr. Decker.

STATEMENT OF DR. JAMES F. DECKER, ACTING DIRECTOR, OFFICE OF ENERGY RESEARCH, U.S. DEPARTMENT OF ENERGY, WASHINGTON, DC, ACCOMPANIED BY DR. WILMOT N. HESS, ASSOCIATE DIRECTOR FOR HIGH ENERGY AND NUCLEAR PHYSICS

Dr. **Decker**. Thank you very much.

Madam Chairman, members of the subcommittee, I am pleased——

Mrs. **Lloyd**. Dr. Decker, would you please pull the microphone just a little closer, please, sir. Thank you.

Dr. **Decker**. I am pleased to be here to discuss the Department of Energy's——

Mrs. **Lloyd**. And would you identify your colleague.

Dr. **Decker**. Yes, I will. I have with me Dr. Wilmont Hess, who is the Associate Director for High Energy and Nuclear Physics.

Mrs. **Lloyd**. We are happy to have you with us as well.

Dr. **Decker**. I am pleased to be here to discuss the Department of Energy's fiscal year 1989 budget request for its General Science Programs, specifically High Energy Physics and Nuclear Physics.

The High Energy and Nuclear Physics Programs support fundamental basic research that increases our scientific knowledge base today and will result in economic benefits in the future. The goal of high energy physics is to find and understand the fundamental building blocks of matter and the forces that govern their behavior. The goal of the Nuclear Physics Program is to understand the structure and interactions with atomic nuclei. Understanding these phenomena is essential for a basic understanding of the world around us.

High Energy and Nuclear Physics have also had enormous influence over other branches of science and technology. Examples include nuclear energy, nuclear medicine, and microelectronics and many others. Even the exotic anti-matter particle, the positron, has found important medical applications in Positron Emission Tomography.

Before discussing this year's budget request, I will briefly touch on some recent accomplishments of these programs.

The Tevatron at Fermilab is the world's most powerful accelerator. It can be operated either as a fixed-target accelerator or as a collider for different types of experiments. It recently completed its first run as a collider at the world record energy of 1.8 trillion electron volts.

Mrs. **Lloyd**. Dr. Decker, we are going to experiment here and see if we can just turn the microphone off and see what happens. We are getting such a feedback, we are going to have to do a little bit of trial and error here and see what works. Please proceed. At our high energy physics hearings, we can't get our microphone to work.

Dr. **Decker**. The Tevatron accelerator recently completed its first run as a collider at a world record energy of 1.8 trillion electron volts. Scientists are now coming to Tevatron from all over the world to study processes inaccessible at any other accelerator.

The Tevatron has also completed a very successful eight-month-long fixed-target run which involved eleven major experiments and generated data for about 100 doctoral theses.

Construction on the Stanford Linear Collider, the world's only linear collider, was completed last March. Beam testing and tuneup are now in progress, and first experimental operations are expected to start soon. Collisions of electrons against positrons in this accelerator will test the theory that unifies the electromagnetic force and the weak force.

At Brookhaven National Laboratory, we recently completed modifications to the Alternating Gradient Synchrotron that allow heavy ions to be accelerated. Brookhaven has already achieved its first results with collisions of oxygen atoms. These collisions are giving us an early glimpse of the nuclear phenomena that the Relativistic Heavy Ion Collider is intended to explore in the future.

I would also like to mention an accomplishment based on one of nature's own particle accelerators. Last February, deep in a salt mine under Lake Erie, a detector recorded neutrinos that emerged from the brightest supernova in the last 363 years. This observation provided valuable data on the dynamics of exploding stars and it inaugurated the new field of neutrino astronomy. We built this detector to study spontaneous proton decay, but it proved to be a good instrument for neutrino astronomy.

Our fiscal year 1989 budget request for High Energy Physics emphasizes exploiting the enhanced capabilities of collider facilities at both Fermilab and SLAC. We will also continue construction on the large detectors, D-Zero at Tevatron and SLD at Stanford to keep these accelerators in the forefront during the early 1990s.

Our request also includes funds to complete the Fermilab Central Computing Upgrade and to continue construction of the AGS booster at Brookhaven that will be completed in 1991.

Most important for the future of High Energy Physics is the Superconducting Super Collider. This Committee held a hearing on the Super Collider last week, and two weeks ago, the Subcommittee on International Scientific Cooperation held a hearing on the international aspects of SSC. Therefore, I will keep my remarks brief today.

As I have just indicated, we have completed major upgrades at both Fermilab and SLAC. These new collider facilities will provide the United States with forefront facilities in the near term and allow our high energy scientists to continue to make progress toward understanding the basic constituents of matter.

However, if we look ahead toward the mid-1990's, our present accelerators will no longer be producing significant new knowledge. Based on current theory, we know that new phenomena not accessible to the present accelerators must appear, and the SSC is aimed at addressing these new phenomena. The SSC will be necessary to maintain an internationally competitive program at the scientific frontier.

Our request increases the R&D funding for this project from $25 million in fiscal year 1988 to $64 million in fiscal year 1989. We are also requesting $283 million to begin construction. Specifically, we are asking for funds for detailed design of technical systems and conventional systems, long-lead critical path procurements and site preparations.

In order to share the cost of this world class facility, the Department is aggressively seeking international participation on the SSC either through cost sharing or with contributions in kind. I believe that substantial in-kind contributions are likely from several countries, but significant foreign commitments are not expected until Congress demonstrates its support for the project.

I would like to turn now to the Nuclear Physics request. We are asking for funds to continue construction of the Continuous Electron Beam Accelerator Facility, with the completion of this project expected in 1993. This accelerator will provide scientists a new tool to probe the interior of the nucleus and allow them to study not only how neutrons and protons form the nucleus but also how the neutrons and protons are formed from quarks.

We are also requesting funding to continue nuclear physics research in existing facilities and funds to continue research and development on a possible new accelerator, the Relativistic Heavy Ion Collider, at Brookhaven.

This concludes my oral remarks, and I would be pleased to answer any questions the subcommittee might have.

[The prepared statement of Dr. Decker follows:]

Statement of James F. Decker

Acting Director

Office of Energy Research

Department of Energy

before the

Subcommittee on Energy Research and Development

of the

House Science, Space and Technology Committee

March 30, 1988

Madam Chairman and Members of the Subcommittee:

It is a pleasure to appear here today to present the FY 1989 budget request for the High Energy Physics and Nuclear Physics programs. Although these programs seek the answers to the most basic questions at the frontier of science, the technology and knowledge developed as a result of this research have contributed significantly not only to energy resource development, but to education, health, industry and national defense. Contributions to the economic growth and prosperity of the Nation have come directly from the results of the research, from technological spinoffs and from the training of tomorrow's scientists through participation of university graduate students in the research. Through science and technology transfer, these ideas and people have made contributions to a variety of industries including medical instrumentation and therapy, control and instrumentation of industrial processes, the production of nuclear energy, and many applications of electronic and computer techniques. We fully expect that these programs will continue to add to our understanding of our physical world and to contribute materially to the well-being of the Nation.

In FY 1989, funding for these programs is requested under two separate appropriations: General Science and Research and a new appropriation entitled Basic Research User Facilities. The new Basic Research User Facilities (BRUF) appropriation includes funding for construction, operation, and maintenance of the Office of Energy Research's major "user facilities." Construction and operation of these large, complex and expensive facilities requires sustained, central federal support since they are far too large and costly to expect any single non-federal research institution to provide such facilities for the benefit of the scientific community. These facilities provide a unique national resource for forefront research in areas related to the use and production of energy. Their continued operation is essential to ensure a continuous supply of new knowledge, trained personnel and new directions for the energy well-being of the U.S. and to support the technology base that is vital to the Nation's economic future. It is important to note that the BRUF funds, which include operating expenses, capital equipment and construction, provide only for the construction, operation, and maintenance of the facilities. The High Energy Physics and Nuclear Physics research conducted in these facilities continues to be funded under the General Science and Research appropriation. The total amount requested in FY 1989 for the programs which I am discussing today is $1,197.1 million, an increase of $392.6 million over the FY 1988 appropriation of $804.5 million.

HIGH ENERGY PHYSICS

The main goal of high energy physics research is to develop new knowledge and a better understanding of the nature of matter and energy as well as the basic forces that govern all processes in nature. One of the major current objectives of high energy physics research is to develop a unified description, or single theory, that would describe all the interactions of matter and energy in the universe. Another major objective is to search for the most fundamental constituents of matter. As with any exploratory field of research, one can also anticipate new and totally unexpected discoveries.

In recent years, high energy physicists have developed an increasingly better understanding of the forces of nature and the unifying connections among them. The four known fundamental forces are the electromagnetic force, the weak force, the strong force, and the gravitational force. The search for a unified, or single, theory has been a reliable guide to physics research. It is a search for linkages between apparently diverse phenomena in an effort to discover underlying simplicity. A part of the progress in high energy physics has been the conceptual unification of the weak nuclear force and electromagnetic forces into a single "electroweak" framework. In addition, a theory of the strong force has emerged which is consistent with experimental results. There is increasing anticipation that the unification of the strong nuclear and the electroweak forces into one "grand unified" framework may be possible, thus reducing the apparent number of forces in nature to two. The ultimate goal is a "super-grand" unification that would bring all of the forces in nature into a single unified framework.

This picture of nature in terms of the electroweak and strong forces and a small set of fundamental constituents is known as the Standard Model. The most significant recent experimental results all reinforce the predictions of the Standard Model. Although no deviations from the Standard Model have been found, scientists believe that it cannot be the final answer. For example, it does not explain the origin of mass and it does not include gravity. Experiments using newly available research capabilities at Fermi National Accelerator Laboratory (Fermilab) and the Stanford Linear Accelerator Center (SLAC) are testing the Standard Model and searching for phenomena that do not conform to that Model, as well as for phenomena predicted by newer theories.

The ability to carry out forefront exploratory research on the physics frontier is critically dependent on the experimental capabilities of the accelerators, colliding beam devices and large particle detectors. Provision of upgraded and new facilities on a timely basis, thus, is an important consideration. There are three DOE supported accelerator centers, Fermilab, Brookhaven National Laboratory (BNL), and SLAC, each of which provides world-unique capabilities. Two major upgrades of U.S. High Energy Physics facilities, the Stanford Linear Collider (SLC) and the Fermilab Tevatron Collider, which recently came into operation, will be available to produce strong research output in FY 1989. These facilities will keep the Program highly competitive and at the cutting edge for the next several years. To maintain an internationally competitive program at the scientific frontier in the mid 1990's, activities leading to the construction of a new major facility, the Superconducting Super Collider (SSC), have been initiated.

University scientists carry out over three fourths of the experimental and theoretical research in the field, much of it at the major accelerator facilities. Universities not only provide intellectual leadership for the field, but also play a major role in the training of highly skilled scientists and engineers. In fact, many of these experts are eagerly sought by industry and other scientific disciplines. As they apply their high energy physics training in other areas, these scientists contribute significantly to the transfer of technology to other fields. For example, the 1979 Nobel Prize in Medicine was shared by Alan Cormack who applied techniques from his experience in bubble chamber data analysis in the High Energy Physics program to develop the computerized axial tomography technique for medical diagnosis. This technology, commonly known as the CAT scan, is in widespread use today.

Before turning to a discussion of the FY 1989 budget request, I would like to summarize some of the progress made in 1987 at the major High Energy Physics research facilities. At the Tevatron at Fermilab, the new capabilities for proton-antiproton colliding beam experiments achieved record high values of beam energy and intensity, with both beams operating at 900 billion electron volts (GeV) for colliding beam experiments. The antiproton source set a new world record by repeatedly accumulating more than 10 billion antiprotons per hour. Progress also continued on the two major colliding beam detector facilities that will measure the results of collisions at the Tevatron's new energy levels. During its initial physics run at Fermilab, the Collider Detector (CDF) fully met all its technical goals. Besides completing its first checkout and engineering run, CDF physicists were able to record more than 400,000 triggered events on about 500 magnetic tapes--enough data to ensure new insight into the unexplored terrain of antiproton-proton interactions at the 1.8 trillion electron volts (TeV) reaction energy. In addition, fabrication of the massive, 5,500 ton D-Zero detector for the Tevatron collider advanced well in 1987 and remains on schedule for full operations in 1990 when it will take data simultaneously with the CDF and, thereby, double the Tevatron's collider physics productivity.

The just-completed Tevatron fixed target program run has been the most productive one since the superconducting accelerator was first brought into operation in 1983. In just over 30 weeks of operation at its world record beam energy of 800 GeV for fixed target experiments, the Tevatron has accelerated almost two billion billion (2×10^{18}) protons. Eleven major fixed target experiments, involving about a thousand physicists and graduate students, have been completed. Almost a hundred Ph.D. theses at several dozen major universities are anticipated based on analyses of the data collected during these experiments. Four new fixed target beam lines were commissioned and brought into operation for data collection during this period. In addition, essential calibration tests of apparatus and R&D efforts were successfully carried out in two test beams which operated parasitically during the fixed target physics run. Extensive studies and commissioning work were also carried out using the Fermilab Antiproton Accumulator ring in a new mode of operation in which it can provide a beam of antiprotons for a fixed target experiment when not needed for the collider physics program. In summary, we have just concluded the most productive and successful fixed target operating period ever conducted at Fermilab.

In 1987, the Stanford Linear Accelerator Center's ability to study collisions of electrons with positively charged particles (positrons) significantly increased with the completion of the Stanford Linear Collider (SLC) project. Beam testing and tune-up are in progress now. Initial operation for research, at a reaction energy of 94 GeV, is expected to begin very soon. The higher energies available in the SLC will enable scientists to conduct important new experiments, particularly with regard to the electroweak force. In preparation for first collisions of 47 GeV electrons and positrons, the upgraded Mark II Detector was installed in the SLC interaction region and tested with cosmic rays during 1987. It is now ready to capture results of collisions in the SLC's unprecedented electron-positron energy range.

Substantial progress was made in the fabrication of the Stanford Large Detector (SLD) during 1987. The SLD is a full-scale detector, designed specifically to optimize the physics output from the electron-positron collisions in the SLC.

At Brookhaven National Laboratory the major technical design and the conventional construction design efforts for the Alternating Gradient Synchrotron (AGS) Accumulator/Booster were completed and the tooling and initial procurements for the 202-meter ring of beam-bending magnets began. This additional particle injector to the AGS will increase the intensity of both the AGS proton beams by 400 percent and the intensity of polarized proton beams by 2000 percent. This enhancement will permit researchers at Brookhaven to explore previously inaccessible areas of the subatomic world and will significantly increase the rate of data collection.

FY 1989 HIGH ENERGY PHYSICS BUDGET REQUEST

The FY 1989 request for the research portion of High Energy Physics is $220.4 million. Of the total amount, $144.9 million is for Operating Expenses, $66.1 million is for Capital Equipment and $9.4 million is for Construction (Tables 1 & 2). This request falls under the General Science and Research appropriation. I will discuss the Basic Research User Facilities request for High Energy Physics and for the Superconducting Super Collider after I describe the budget request for our High Energy Physics research program.

Table 1
General Science and Research
High Energy Physics
Budget Authority
($ in millions)

	FY 1987	FY 1988	FY 1989 Request
Operating Expenses			
Physics Research	$109.0	$116.7	$123.8
High Energy Technology	21.4	20.3	21.1
Subtotal	$130.4	$137.0	$144.9
Capital Equipment	59.0	63.8	66.1
Construction	12.5	16.6	9.4
Total High Energy Physics	$201.9	$217.4	$220.4

Table 2
General Science and Research
High Energy Physics
Budget Authority
($ in millions)

Construction

Project	TEC	FY 1988	FY 1989 Request
Central Computing Facility (86-R-104)	$24.1	$ 11.0	$ 3.6
General Plant Projects (GP-E-103)	5.8		5.8
General Plant Projects (GP-E-103)	5.6	5.6	-
Total Construction		$ 16.6	$ 9.4

The Operating Expenses request supports university and laboratory research groups who carry out experimental and theoretical research in high energy physics as well as detector R&D studies to develop new and advanced concepts and technologies. FY 1988 will be a year of strong research output from the new Tevatron and SLC colliders and new Tevatron fixed target capabilities. Research activity planned for FY 1989 is expected to be very productive as the data collected in FY 1988 are analyzed and these new facilities operate in an intensive data-taking mode.

The FY 1989 High Energy Physics Capital Equipment request of $66.1 million will provide the particle detection apparatus and data analysis systems essential to forefront high energy physics research. In FY 1989, priority will be given to continued progress on the fabrication of the SLAC Large Detector for the Stanford Linear Collider and the D-Zero Detector for the Tevatron collider. With this continued progress, first physics research with these detectors is planned to be started early in FY 1990 and the detectors can be completed by the end of FY 1990.

The FY 1989 Construction request is $9.4 million. This request includes final funding for the central computing upgrade at Fermilab ($3.6 million) which is scheduled to be completed in 1989. This upgraded computing capability is required to analyze the large volume of new physics data coming from the Tevatron program. This request also provides $5.8 million for General Plant Projects at Brookhaven National Laboratory which are required to keep the general plant (e.g., buildings, roads and utilities) in good operating condition.

BASIC RESEARCH USER FACILITIES--HIGH ENERGY PHYSICS (BRUF-HEP)

The ability to carry out forefront exploratory research in high energy physics is critically dependent on the effective operation of the major accelerator and collider facilities. The new BRUF appropriation provides funds to build, operate, and maintain these facilities. The total BRUF-HEP request for FY 1989 is $346.4 million. Of that total amount, $301.7 million is for Operating Expenses. The Capital Equipment request is for $13.7 million; and the Construction request is $31.0 million (Tables 3 & 4).

Within the Operating Expenses request, the highest priority will be given to operating the new world forefront research capabilities of the Stanford Linear Collider and the Tevatron proton-antiproton collider and fixed target programs. Operation at SLAC of the upgraded Positron-Electron Project collider with the improved Time Projection Chamber detector and operation at BNL of the Alternating Gradient Synchrotron program on rare kaon decay will also be very important. Accelerator R&D, including studies of advanced accelerator concepts, will be supported at about the same level of effort as in FY 1988.

The Capital Equipment request of $13.7 million is needed to maintain and enhance the scientific capability of the accelerators and colliders and to provide the secondary beam line components and portable shielding needed to do high quality high energy physics experiments. Funding in FY 1989 will provide for support of planned accelerator maintenance, upgrading and modifications at Fermilab, SLAC and BNL.

Table 3
Basic Research User Facilities (BRUF)
High Energy Physics
Budget Authority
($ in millions)

	FY 1987	FY 1988	FY 1989 Request
Operating Expenses			
Facility Operations	$204.3	$233.3	$256.6
High Energy Technology	39.1	43.4	45.1
Subtotal	$243.4	$276.7	$301.7
Capital Equipment	$ 11.1	12.9	13.7
Construction	18.9	24.6	31.0
Total BRUF-HEP	$273.4	$314.2	$346.4

Table 4
Basic Research User Facilities (BRUF)
High Energy Physics
Budget Authority
($ in millions)

Construction

Project	TEC	Prior Year	FY 1988	FY 1989 Request
Accelerator Improvements and Modifications (89-R-301)	$11.7	-	$ -	$ 11.7
Accelerator Improvements and Modifications (88-R-101)	11.2	-	11.2	-
General Plant Projects (GP-E-302)	5.3	-	-	5.3
General Plant Projects (GP-E-103)	5.1	-	5.1	-
AGS Accumulator/Booster (86-R-105)	31.7	$4.4	8.3	$ 14.0
Total Construction		$4.4	$ 24.6	$ 31.0

Of the $31.0 million Construction request, $14.0 million will provide for continued construction of the AGS Accumulator/Booster at BNL. This project, which is scheduled for completion in FY 1991, will improve the performance and capabilities of the AGS and will significantly increase the data collection rate for the experimental program already planned and underway. The Construction request also includes funds for a constant level of effort for *Accelerator Improvements and Modifications Projects ($11.7 million) that are* required to maintain the scientific effectiveness and the operating reliability and efficiency of the accelerator and colliding beam facilities. Finally, the request provides $5.3 million for a constant level of effort for General Plant Projects at Fermilab and SLAC that are required to keep the general plant of the laboratories (e.g., buildings, roads and utilities) in good operating condition.

BASIC RESEARCH USER FACILITIES--SUPERCONDUCTING SUPER COLLIDER (BRUF-SSC)

As I noted earlier, experimental research in high energy physics requires the use of large particle accelerators, colliding beam devices and detectors. To extend the research frontier into a region never before studied and where major breakthroughs in understanding are firmly anticipated, larger, more powerful accelerators are required. Major upgrades of the Stanford Linear Collider at SLAC and the Tevatron Collider at Fermilab will keep the U.S. High Energy Physics program internationally competitive and at the cutting edge of physics research for the next several years. But even these facilities will not reach high enough energies to allow physicists to investigate the region where major breakthroughs are anticipated. There are many important unanswered questions such as whether there are even more fundamental particles than quarks and leptons, what determines their basic properties and whether there are new, undiscovered forces of nature. To advance the research frontier, a new, more powerful accelerator is needed. The proposed Superconducting Super Collider is that facility.

As Secretary Herrington has noted, this Presidential initiative is a watershed for America's scientific and technological leadership and another clear sign that this Administration is committed to keeping this Nation on the cutting edge of world leadership and competitiveness.

The SSC is essential if we are to maintain leadership in high energy physics research into the 21st century. In the past, U.S. leadership has been maintained by successive commitments to more powerful, sophisticated accelerators. The SSC represents the next generation of advanced accelerators. It will be built using existing, state-of-the-art technology and will require the best minds in engineering and computer sciences for its construction and operation. The technology developed in building the SSC is expected to lead to industrial innovation in such areas as computing and electronics. In this age of keen international competition, the SSC is vital to the United States' capability to maintain its leadership in the laboratory and the marketplace.

Another important benefit of the SSC is that it will be a valuable training ground for American scientists and will attract many of the world's leading physicists to live and work in the United States. The SSC would be utilized by over 100 American university-based research teams, thereby continuing the precedent of accelerator facilities as a career launching pad for young scientists and engineers. The SSC would be a viable inspiration for young people to pursue careers in advanced science and technology by challenging a new generation to unlock the secrets of nature.

The FY 1989 request includes $363.0 million for the Superconducting Super Collider (Table 5). The heart of the SSC will be two rings containing about 10,000 superconducting magnets located in a racetrack-shaped tunnel about 53 miles in circumference and 10 feet in diameter. There will be four interaction regions at which experiments will be carried out with detectors that record the results of the collisions between beams of protons, each having energy levels of 20 TeV. The SSC will be a powerful basic research tool that will significantly extend the frontiers of understanding of the basic nature of matter and energy. We also expect that the SSC will produce significant research results and technological spinoffs. The Department is proceeding on course with its plan to select the site for the SSC in January 1989. As you know, the Department announced its list of seven best qualified sites in January. Detailed analysis of these sites is now in progress. In addition, the Department is actively seeking international collaboration and cost-sharing with other countries.

The SSC request includes $64.0 million in Operating Expenses. This will permit R&D on SSC technical systems to proceed at a substantially enhanced level in FY 1989. The work will focus on optimizing the design of the magnets and on industrialization of the magnet fabrication process.

Table 5
Basic Research User Facilities
Superconducting Super Collider (SSC)
Budget Authority
($ in millions)

	FY 1987	FY 1988	FY 1989 Request
Operating Expenses	$ 20.0	$ 25.0	$ 64.0
Capital Equipment	-	-	16.0
Construction	-	-	283.0
Total SSC	$ 20.0	$ 25.0	$363.0

In FY 1989 the SSC will have its first significant capital equipment requirements. The $16.0 million Capital Equipment request will provide equipment required to support the magnet R&D program for testing and analysis of magnets and for testing various other technical components and systems. The requested funds will provide for such equipment as power supply systems; a large helium refrigerator; test, control and measurement equipment; and components for detector development and prototyping.

The Construction request of $283.0 million will allow initial construction activities to proceed on a broad front in FY 1989. The request includes $39.0 million for detailed engineering design of technical systems and conventional facilities, $60.0 million for long-lead items for power stations and utilities distribution systems, $27.0 million for site preparation, $55.0 million for injector technical components which are early critical path items, $65.0 million for long lead procurements for collider components (including magnet tooling, superconducting materials and magnet steel) and $37.0 million for project management, support equipment and rental space.

In summary, I believe that the SSC demonstrates clearly the commitment of President Reagan and his Administration to pursue new initiatives in science and technology and, in doing so, to enhance the economic and technological health of the United States.

NUCLEAR PHYSICS

The goal of the Nuclear Physics program is to understand the structure and interactions of atomic nuclei. This understanding is essential to unraveling the mysteries of the world around us because nuclear processes determine the physical characteristics of our universe. For this very reason, advances in nuclear physics have both short and long-term effects well beyond the immediate boundaries of the field.

The results of nuclear physics research have made many contributions to our society and economy. For example, every hospital contains numerous examples of nuclear science at work. Especially prominent is the use of radioactivity and nuclear beams for diagnosis and therapeutic treatment of cancer. Nuclear energy makes a substantial contribution to the Nation's energy supply; the smoke detectors we have in our homes contain radionuclides; nuclear techniques in the form of ion implantation have revolutionized the semiconductor industry; and nuclear techniques for geophysical exploration, testing of materials, and archeological dating and siting are widely used.

The Nuclear Physics program continues to increase our knowledge of atomic nuclei as well as our capability to expand that knowledge base. Scientists now know that neutrons and protons, the constituents of the nucleus that are called nucleons, are composed of smaller constituents called quarks. These quarks are bound together in tightly knit groups of threes. However, scientists have not been able to isolate quarks outside the nucleus. It is as if quarks were tied together by elastic strings that cannot be broken. This confining mechanism forms the basis of the newest theory of the strong nuclear force, quantum chromodynamics.

The total Nuclear Physics program develops and supports a wide range of large and complex accelerator facilities which provide the beams of particles upon which the experiments are based. The diverse aspects of nuclear experimental research are addressed by using beams of light ions, heavy ions, electrons and protons over a wide range of particle energies. The collision of these beams with targets of atomic nuclei is the primary means by which scientists learn about the structure and forces acting within nuclei.

Among the program's accomplishments in 1987, the first gamma ray beam from the Laser-Electron-Gamma-Source (LEGS) at Brookhaven National Laboratory was produced. This unique facility produces gamma rays at a well-defined energy by bouncing ultraviolet light produced in a laser off the electrons in the circulating beam at Brookhaven's National Synchrotron Light Source (NSLS). The scattered light emerges witn a much higher energy than it started with (thus becoming gamma rays with an energy of 300 million electron volts) as a result of the collisions with the electrons. By detecting the electrons from the NSLS beam which have been hit by the light, scientists can select a beam of gamma rays of the appropriate energy for use in experiments. LEGS is unmatched in the intensity and purity of the gamma ray beam it will provide for research. In addition, the gamma rays are 100 percent polarized, adding the unique aspects of spin to the photo-nuclear experiments planned for the new facility.

Also in 1987, Argonne's superconducting ATLAS system reached the limits of its current ion source and injector by accelerating ions with atomic masses of more than 120. ATLAS was the world's first working accelerator to use superconducting radio frequency cavities and has become a prototype for many other facilities throughout the world. A new positive-ion injector is under development that eventually will enable ATLAS to accelerate ions as massive as uranium, which is the heaviest stable element. In addition, a new recoil mass spectrometer is being installed to make most effective use of the new beams.

In addition to accelerator facilities, the Nuclear Physics and High Energy Physics programs support "nonaccelerator" experiments such as those to measure the lifetimes of protons and radioactive nuclei, to search for exotic particles and unusual modes of decay, or to open new windows on the universe through information provided by neutrino detectors. Using such detectors, physicists supported by the High Energy and Nuclear Physics program gathered important information about one of 1987's most spectacular scientific events. The brightest exploding star in the last 363 years, called a supernova, was observed several hours before its visible light reached the earth by one detector located deep in a salt mine under Lake Erie and a second which was deeply buried in the mountains of Japan. The detectors recorded a burst of neutrinos, which is the first time that neutrinos from outside our solar system have been observed. Neutrinos are the most abundant particles in the universe, but scientists know relatively little about their properties. Observation of the 1987 supernova not only provided information on the stability and mass of neutrinos, but also provided a key to the dynamics of the great explosion which marked the end of this star's life.

FY 1989 NUCLEAR PHYSICS BUDGET REQUEST

The FY 1989 budget request for the research portion of the Nuclear Physics program is $141.4 million. Of that total, $118.1 million is for Operating Expenses, $17.5 million is for Capital Equipment and $5.8 million is for Construction (Tables 6 & 7). I will discuss the Basic Research User Facilities request for Nuclear Physics after describing the Nuclear Physics research program request.

The FY 1989 Operating Expenses request will provide for continued experimental research on the basic structures and characteristics of nuclei and for the investigation of quarks within nuclei and of the fundamental forces of nature acting within extended nuclear matter. Research in low and medium energy nuclear physics, in heavy ion nuclear physics and in nuclear theory will continue at approximately the FY 1988 level. This research will focus on current problems of high scientific and technological interest and will continue to prepare the program to exploit major new facilities. Funding is also devoted to maintaining the effective operation of the upgraded accelerators at the University of Washington and Yale University, of the superconducting cyclotron at Texas A&M constructed with State and private funds, and of the Tandem/AGS high energy heavy ion facility at Brookhaven National Laboratory.

Operating funds also will support continued vigorous R&D aimed at providing a solid scientific and technical base for the planned relativistic heavy ion collider, one of four facilities identified by the scientific community as being critical to the future needs of the Department's basic research

Table 6
General Science and Research
Nuclear Physics
Budget Authority
($ in millions)

	FY 1987	FY 1988	FY 1989 Request
Operating Expenses			
Medium Energy Nuclear Physics	$ 32.7	$ 35.5	$ 37.5
Heavy Ion Nuclear Physics	36.4	40.9	43.3
Low Energy Nuclear Physics	24.0	26.2	26.3
Nuclear Theroy	10.0	10.5	11.0
Subtotal	$103.1	$113.1	$118.1
Capital Equipment	$ 14.8	$ 16.6	$ 17.5
Construction	4.3	5.2	5.8
Total Nuclear Physics	$122.2	$134.9	$141.4

Table 7
General Science and Research
Nuclear Physics
Budget Authority
($ in millions)

Construction

Project	TEC	FY 1988	FY 1989 Request
Accelerator Improvements and Modifications (89-R-201)	$ 2.6	-	$ 2.6
Accelerator Improvements and Modifications (88-R-201)	2.3	$ 2.3	-
General Plant Projects (GP-E-300)	3.2	-	3.2
General Plant Projects (GP-E-300)	2.9	2.9	-
Total Construction		$ 5.2	$ 5.8

programs. Special emphasis will be made to accommodate training of young scientists and to ensure that the nuclear theory program accommodates the latest scientific priorities.

The FY 1989 Capital Equipment request of $17.5 million is needed to provide for particle detection systems, data acquisition and analysis systems and instrumentation to improve the performance of Nuclear Physics accelerators. These funds are essential for effective use of the accelerator and detector facilities operated by the Nuclear Physics program. The FY 1989 request will maintain the overall level of effort and will provide for general purpose equipment to meet the laboratory-wide needs of Lawrence Berkeley Laboratory.

The Construction request of $5.8 million includes $2.6 million for Accelerator Improvements and Modifications (AIM) and $3.2 million for General Plant Projects (GPP). These projects are needed to maintain the scientific effectiveness, reliability and efficiency of Nuclear Physics facilities. GPP projects focus on general laboratory facilities while AIM projects address the need for improvements to research accelerators and related experimental facilities.

BASIC RESEARCH USER FACILITIES--NUCLEAR PHYSICS (BRUF-NP)

The Nuclear Physics program requires the effective operation and maintenance of the accelerator facilities which provide the beams of particles upon which the experiments are based. The BRUF-NP program operates and maintains the following scientific user facilities: the Clinton P. Anderson Meson Physics Facility (LAMPF) at Los Alamos National Laboratory, the Bevalac at Lawrence

Berkeley Laboratory, and the Tandem/AGS at Brookhaven National Laboratory. This program also funds construction of the major new facilities required to address the most important scientific questions. To meet this objective, construction of the Continuous Electron Beam Accelerator Facility (CEBAF) project was initiated in FY 1987.

The FY 1989 BRUF-NP request is for $122.7 million. Of that amount, $75.0 million is for Operating Expenses; $1.0 million for Capital Equipment and $46.7 million is for Construction (Tables 8 & 9).

The Operating Expenses request will support medium energy physics operations and facility maintenance at approximately the FY 1988 level of activity. The $49.6 million requested for this subprogram will support the operation of LAMPF as well as the light ion operation of the Bevalac. R&D activities required for the construction of CEBAF and preparation for operation of the laboratory are also carried out under the medium energy subprogram. The operation of heavy ion nuclear physics facilities at BNL and LBL will be supported at approximately the FY 1988 level of activity.

The $1.0 million Capital Equipment request is needed to provide for instrumentation to improve and maintain performance of Nuclear Physics accelerators at BNL, LBL and LANL.

Of the total Construction request of $46.7 million, $44.5 million is for continued construction of CEBAF. The main research tool at CEBAF will be an accelerator with electron beams in the energy range of 0.5 to 4.0 GeV. Its combination of high-energy, high-current, and continuous beam with excellent

Table 8
Basic Research User Facilities (BRUF)
Nuclear Physics
Budget Authority
($ in millions)

	FY 1987	FY 1988	FY 1989 Request
Operating Expenses			
Medium Energy Nuclear Physics	$ 47.9	$ 48.5	$ 49.6
Heavy Ion Nuclear Physics	23.9	24.3	25.4
Subtotal	$ 71.8	$ 72.8	$ 75.0
Capital Equipment	$ 1.1	$ 1.1	$ 1.0
Construction	19.8	36.3	46.7
Total BRUF-NP	$ 92.7	$110.2	$122.7

Table 9
Basic Research User Facilities (BRUF)
Nuclear Physics
Budget Authority
($ in millions)

Construction

Project	TEC	Prior Year	FY 1988	FY 1989 Request
Accelerator Improvements and Modifications (89-R-501)	$ 1.7	-	-	$ 1.7
Accelerator Improvements and Modifications (88-R-201)	2.1	-	$ 2.1	-
Continuous Electron Beam Accelerator Facility (87-R-203)	265.0	$ 16.2	33.5	44.5
General Plant Projects (GP-E-500)	0.5	-	-	0.5
General Plant Projects (GP-E-300)	0.7	-	0.7	-
Total Construction		$ 16.2	$ 36.3	$ 46.7

beam quality is expected to revolutionize the production and collection of data for nuclear physics research. When CEBAF's energy is at its lowest, the electron beam will interact with the protons and neutrons that are the building blocks of nuclei. When its energy is at the high range, the electron beam from the accelerator will probe the underlying quark structures of protons or neutrons, providing a direct test of the newest concepts of nuclear matter, including quantum chromodynamics. Thus, the facility will provide the world's first capability to access the critical transition region between the traditional and emerging descriptions of nuclear matter.

The $44.5 million in FY 1989 Construction funds for CEBAF will be used for major hardware procurement of radiofrequency cavities and the central helium liquifier. Construction of the beam enclosure tunnel and support structures will continue. In addition, initial procurement of beam control apparatus and prototype power supplies will take place. Progress in FY 1988 includes complete preparation of the site, initial construction of the beam enclosure tunnel, procurement and testing of prototype superconducting accelerator elements, rehabilitation of an existing laboratory building, and approved architectural designs for the beam enclosure and office building. The remainder of the Construction request will support Accelerator Improvements and Modifications ($1.7 million) and General Plant Projects ($.5 million) at the existing facilities.

GENERAL SCIENCE PROGRAM DIRECTION

he FY 1989 budget request for General Science Program Direction is $3.2 million. This request is under the General Science and Research appropriation. The requested funds are required to provide for the salaries, benefits, travel and other expenses associated with 46 full-time equivalents in the Office of High Energy and Nuclear Physics and associated support staff required to administer these programs.

That concludes my statement. I would be happy to answer questions.

DISCUSSION

Mr. **Chapman** [presiding]. Thank you very much. I appreciate your testimony today. How do you feel about the comments that we have heard regarding the National Science Foundation dropping its support for these programs? Would that be appropriate if they did that?

Dr. **Decker**. At the Department of Energy, we certainly would not want to see the National Science Foundation drop its support for these programs. If you take high energy physics, it is true that the National Science Foundation provides only ten percent of the support for that field.

However, their support amounts to 30 percent of the university activities in the field so they are a very important player in university research. Another reason that I would not like to see the National Science Foundation get out of these fields is that I think that it is very useful to have more than one agency fund fields like nuclear physics and high energy physics.

It is, I think, just a better management situation to have more than one agency involved in these important areas of basic research.

Mr. **Chapman**. Would it be possible within the Department of Energy to absorb it if that kind of support were lost? Could you absorb the programs that they currently undertake and fund?

Dr. **Decker**. No, sir, not with our present budget.

Mr. **Chapman**. Dr. Decker, as you know, the House Budget Resolution that recently was passed has provided $100 million dollars for General Science and Research programs which is less than the request although the Senate has yet to complete its budget.

It is very difficult to imagine that a significant change in this growth allowance will occur in the final budget resolution that this Congress approves. This is a figure that is substantially below the $393 million dollar growth that you have proposed in your fiscal year 1989 budget request.

Should the Congress not in its Budget Resolution increase substantially beyond the House-passed level, does the Department have a back-up plan that would permit a continuation of the SSC at this reduced budget level and be able to maintain as your written testimony which I reviewed as well as the testimony of a number of other witnesses who are going to be here today say that SSC should not be funded if it results in any reduction in the level of research that is being conducted in the other areas of physics? What is the plan if these funds are not received?

Dr. **Decker**. I would agree with that position. The highest priority has to be on a continuation of the present research programs. SSC is not to be funded at the expense of the ongoing scientific programs.

Mr. **Chapman**. What is the back-up position then? I would assume that what you are saying without saying it would be a reduction in the appropriations for SSC?

Dr. **Decker**. It would have to be.

Mr. **Chapman**. At what level and again, in the written testimony, I don't recall if it was yours or some of the other witnesses, but at what level of funding does any funding become meaningless or does that occur with the SSC project?

Dr. **Decker**. I think, if we wind up with a substantially reduced budget in SSC, then our emphasis has to be on the research and development program that we would want to continue that forward as our highest priority. It would mean delaying the project obviously at least a year.

Mr. **Chapman**. As I reviewed the written testimony today it seems that there is significant new hardware and programs and research that can be conducted in fiscal year 1989, and perhaps in 1990 and 1991, and in the next three to five years perhaps because of the work that has been done through the Department of Energy and through our research facilities in the physics area that is going to provide significant and meaningful experimentation and research efforts for the next say three to five years at least.

Should the Congress get off on perhaps maybe the SSC at the expense of the basic research that is in place ready to be conducted with the infrastructure that is already there or about to be there? Do I understand your counsel would be under no circumstances should we reduce in any respect our commitment to the ongoing research and adjust the fund for SSC for 1989?

Dr. **Decker**. Yes, sir.

Mr. **Chapman**. At this time let me defer to my colleague, Mr. Morrison.

Mr. **Morrison**. Thank you, Mr. Chairman. I guess one of my major concerns in this budget area is with the Super Collider in that I am not so sure that support is out there Congressionally for this. We are going to hear in a little while in the testimony from Professor Low a statement that the Super Collider project badly needs a management structure that can sensibly guide the project and speak for it.

I am wondering if you agree with that and if so, what has kept the Department from carrying out a competitive process for this contract?

Dr. **Decker**. I think a management structure is important to the project. It is the Department's intention to move expeditiously to put in place a management organization as soon as we get some favorable indication from Congress that there will be significant support for it in the next year.

Mr. **Morrison**. We will hope that we can assist you in the process of creating and maintaining the support within the Halls of Congress to get on with this important project. I am wondering, I speculated a little bit in my opening statement about the balance between upgrading existing facilities and getting on with new ones. Would you care to expand on that and the process that you have gone through internally in achieving that balance as presented in the budget?

Dr. **Decker**. This is always a difficult set of decisions for us to make, this balance that you are referring to between operating budget for existing facilities and moving forward to build the next generation of scientific facilities that the country needs.

One of the difficulties, of course, is that to build these facilities, which are apparently large, in size takes a considerable amount of time. The Federal budget process is really a long process so one has a fairly long-lead time to deal with. We, of course, get input from the scientific community on these decisions.

We have advisory committees in nuclear science and high energy physics both. We then try to strike, as I say, some reasonable balance between these two kinds of activities within the budget restrictions that we always have to live with.

Mr. **Morrison**. Can you share with us how difficult it was to deal with those budget restrictions, that is, how badly did OMB modify what you really would like to do in this area?

Dr. **Decker**. As you are aware, the Budget Summit, of course, put a pretty tight lid on the 1989 budget, so that just gave us a tough situation to start with. I think there is not much more that I can say about it than the fact that we were all starting with a very difficult budget situation this year.

Mr. **Morrison**. Did OMB live up to the President's commitment that the funding for Super Collider would not be at the expense of other basic programs?

Dr. **Decker**. Absolutely. It is certainly true in the Department of Energy. I was intimately involved in budget discussions across the Department and SSC was a totally separate item and was treated totally separate.

Mr. **Morrison**. Good. Thank you, Mr. Chairman.

Mr. **Chapman**. Dr. Decker, one of the highest priorities in the deliberations of the Nuclear Science Advisory Committee has been the construction of the Relativistic Heavy Ion Collider. No construction funds were asked for in the FY 1989 budget request. This is an essential facility, we understand, in order to sustain a strong U.S. program in heavy ion physics research.

Why has the Department not proposed construction funds for the project in FY 1989?

Dr. **Decker**. The Relativistic Heavy Ion Collider is a very important project for nuclear physics, I certainly agree wholeheartedly with that assessment. The program of research and development has moved quite successfully. There we have demonstrated the superconducting magnets that are needed for that facility. The Department has reviewed the project and it is, I think, in good shape to proceed.

The only reason we have not moved forward it has simply been budgetary and the Department would plan to move forward with it as soon as budgetary conditions will allow.

Mr. **Chapman**. Mr. Fawell? Do you have any questions, please?

Mr. **Fawell**. Thank you, Mr. Chairman. Actually, I think I am just about out of questions to Dr. Decker. We have been in a number of Committee meetings. I guess the only thing that as we look at those operating funds in high energy physics, in regard to the user facilities, if I read these figures correctly there is about a $23 million increase.

Are you satisfied insofar as Fermi is concerned, for instance, and all that we have there in the Tevatron and all the improvements that sufficient operating funds are set for it, so that indeed what we do have can be utilized to the fullest?

Dr. **Decker**. Yes, it is my view that we have sufficient funds to fully utilize the Tevatron capability. I don't think any of our laboratories are fat in terms of the 1989 budget. It is not in a year that one can be, but I believe that there is sufficient funds to fully utilize the facility.

Mr. **Fawell**. Are there any funds in regard to improving the new facilities, an investment which I gather some believe is necessary if we are to maintain the momentum of the Tevatron?

Dr. **Decker**. Yes. We do have funds to continue to upgrade the computer capability at Fermilab, which will be very necessary in getting the full data analysis capability that we need for the new Tevatron collider.

Mr. **Fawell**. Thank you. I have no further questions.

Mr. **Chapman**. Dr. Decker, just one final question, if I may. In reviewing the numbers just in the High Energy Physics budget, if we add SSC and assume that Congress should fund it, we are talking over half a billion dollars for FY 1989 for this area of research. That is an enormous amount of dollars going into not only one scientific discipline but a focused sub-discipline of physics.

Let me ask if the Department has currently either under consideration or negotiation any type of international scientific cooperation in addition to, of course, the work that we conduct at DESY and CERN and the joint efforts there, which basically that is their operations. We don't participate financially in a significant way in that operation.

But what about the SSC in particular? Does the Department have anything in the mill, anything working right now other than just the talk that we would certainly like to have international partners? What are we doing to follow up on that with the SSC to try to somehow bring the international community and share the burden?

Dr. **Decker**. First of all, I'd like to point out that we have had some international participation in the design effort so far, which has been helpful to us. We have had informal discussions with a number of countries over a period of several years regarding their participation in the SSC. We made our first formal approaches to the Economic Summit countries with a letter from Secretary Herrington inviting each of those countries to participate in the project. We then followed up the Secretary's letter with visits to each of those countries. We had discussions at very high levels—minister, vice-minister levels in those countries. We feel that on the whole those discussions were quite positive, that there is, in fact, a lot of interest on the part of other countries to participate in this project.

We do not have commitments at this from any countries. As I say, we are really just at the beginning for formal discussions. We really just opened them; in fact, that occurred in the month of January. But we are continuing our dialogue with them. I think that one of the things that we heard on our visits to these countries is that they certainly will be looking to see what the actions of Congress are on our 1989 budget request, to see whether or not, in fact, the U.S. is going to move forward with the project.

Mr. **Chapman**. One other thought. Let me ask you and I may address this question as well to some other witnesses later, but based on the breakout of the quest for the Super Collider for FY 1989, do you anticipate any problem from the timeline standpoint of where we would like to go with construction of the facility? Any slowdown in that timeline, assuming sufficient funding, that would be the result of at this point technical problems of research and development, with magnet design, with refrigerant design, with anything else—is the Department experiencing or the researchers in the design group I understand have experience some problems, are they of such a magnitude or can you assure the Congress, this Committee, that the problems that have been experienced are not going to ultimately affect the construction schedule of the SSC?

Dr. **Decker**. I don't believe that there are technical problems that are going to affect the SSC schedule. The problems that you are referring to in the magnet program are basically mechanical problems in the magnet. There are several approaches that we have to solve that problem and I firmly believe that in the next six to 12 months that that problem will certainly be solved.

Mr. **Chapman**. Thank you, Dr. Decker. We appreciate your time and certainly your work in this area. Thank you for coming this morning.

[Questions and answers for the record follow:]

HIGH ENERGY PHYSICS

Question 1: The February 12, 1988 "Holifield Tables" indicate that the "A/S REQ" for FY 1989 for the High Energy Physics Program totalled $967.75 million, including $528.1 million for operating expenses and $439.65 million for plant and capital equipment. According to these tables, the Department's FY 1989 request to OMB totalled $929.806 million, including $510.606 million for operating expenses and $419.2 million for plant and capital equipment.

a: What are the specific differences between these two budgets?

Answer: The following table indicates the changes from the Assistant Secretary's budget request to the OMB request.

High Energy Physics Program
(Budget Authority in Thousands)

	FY 1989 A/S Request	FY 1989 Request to OMB	Change
Operating Expenses	$528,100	$510,606	($17,494)
Capital Equipment	112,550	95,800	(16,750)
Construction	327,100	323,400	(3,700)
TOTAL	$967,750	$929,806	($37,944)

OPERATING EXPENSES

The $17,494,000 decrease in Operating Expenses resulted in a reduction of $8,300,000 in Facility Operations (however within the reduced budget priority was given to utilization of the new facilities at Fermilab and SLAC); a reduction of $3,194,000 in Physics Research, approximately consistent with the lower facility operations funding; and a reduction of $6,000,000 in High Energy Technology which eliminated a proposed increase intended to begin support for advanced concept programs entering the experimental verification stage and for investigating means of increasing the productivity of the SLC and Tevatron.

PLANT AND CAPITAL EQUIPMENT

The $16,750,000 reduction in capital equipment impacted plans to accelerate the completion of the D-Zero and SLD major collider detector facilities at Fermilab and SLAC.

A $500,000 reduction (from $14,500,000 to $14,000,000) was made in the AGS Accumulator/Booster construction project at the Brookhaven National Laboratory.

A $1,100,000 reduction in Accelerator Improvements and Modifications required delaying proposed upgrades to the PEP, SPEAR, and SLC colliding beam facilities at the Stanford Linear Accelerator Center and proposed upgrades to the accelerator facilities and experimental facilities at Fermilab and the AGS at Brookhaven National Laboratory.

A $400,000 reduction in General Plant Projects limited planned projects at the Brookhaven National Laboratory, at Fermilab, and at the Stanford Linear Accelerator Center.

A $800,000 reduction eliminated the Central Laboratory Addition project at the Stanford Linear Accelerator Center.

A $900,000 reduction eliminated the project to replace PCB transformers at the Stanford Linear Accelerator Center.

Question 1b: What, if any, differences exist between the Department's request to OMB and the budget submitted to Congress?

Answer: As indicated in the following table there were no differences between the Department's request to OMB, and the budget submitted to Congress.

High Energy Physics Program
(Budget Authority in Thousands)

	FY 1989 Request to OMB	FY 1989 Congressional Request	Change
Operating Expenses	$510,606	$510,606	$0
Capital Equipment	95,800	95,800	0
Construction	323,400	323,400	0
TOTAL	$929,806	$929,806	$0

HIGH ENERGY PHYSICS

Question 2: Please identify all unobligated balances in the High Energy Physics Program.

Answer: The High Energy Physics Program had an unobligated balance totaling $132,859 at the end of FY 1987. These resulted from contract negotiations which were not completed as of the end of FY 1987. The contracts were subsequently awarded, and the funds obligated in early FY 1988.

• SUPERCONDUCTING SUPER COLLIDER

Question 3: Professor Francis Low, Chairman of the DOE's High Energy Physics Advisory Panel says in his prepared testimony which he will give later this morning that "The Super Collider project badly needs a management structure that can sensibly guide the project and speak for it." Do you agree, and if so, what has prevented the DOE from carrying out a competitive procedure to select a contractor?

Answer: Yes, we agree with Professor Low. The Department believes that early selection of the Management and Operations (M&O) contractor is important for the success of the SSC project. We have been reluctant to select a contractor, however, before receiving a positive indication from the Congress on SSC funding for FY 1989.

HIGH ENERGY PHYSICS

Question 4: Since last year's budget authorization hearings, the construction end date for the AGS Accumulator/Booster project at Brookhaven National Laboratory has decreased by 1 quarter (from 3rd Quarter, FY 1991 to 2nd Quarter, FY 1991), the total estimated construction cost has increased by $1.1 million (from $30.6 million to $31.7 million), and the total project cost has increased by $7.554 million (from $31.4 million to $38.954 million). What are the technical reasons for the cost increases?

Answer: The increase of $1.1 million in the total construction costs for the AGS Accumulator/Booster results from a "bottoms up" cost re-estimate performed by Brookhaven National Laboratory and a subsequent in depth review of the cost by the Department of Energy in the spring of 1987. The detailed estimates prepared for the Department of Energy review resulted in increases in several of the technical systems and decreases in others.

The R&D necessary to complete construction was incorrectly reported in the FY 1988 Construction Project data sheet resulting in the substantial increase in total project costs in the FY 1989 data sheet. This increase does not require additional funding, since the R&D has, from the beginning, been planned for and budgeted at the higher level.

HIGH ENERGY PHYSICS

Question 5: For FY 1987 - FY 1989, please provide the information requested in a. - e. below for the AGS facility at Brookhaven National Laboratory.

a: Actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, capital equipment, general plant projects, accelerator improvement projects, and any other funding attributable to the facility. Please indicate the sources of the funds (i.e., High Energy Physics, Nuclear Physics, Basic Energy Sciences, etc.).

Answer: The following table indicates the requested budget profiles in High Energy Physics funds (B/A in thousands of dollars):

	Actual FY 1987	Estimate FY 1988	Estimate FY 1989
Accelerator Operations	$36,500	$39,300	$40,600
In-house Research	4,800	5,100	5,800
Out-of-House Research	2,200	2,100	1,800
Other operating expenses (Technology R&D)	14,100	14,900	14,900
Total Operating	$57,600	$61,400	$63,100
Capital Equipment	$ 5,000	$ 5,000	$ 5,000
Accelerator Improvement Projects	$ 2,100	$ 2,200	$ 2,300
General Plant Projects	100	600	600
AGS Accumulator/Booster	$ 2,500	$ 8,300	$14,000
Total Construction	$ 4,700	$11,100	$16,900
Total Laboratory Funding	$67,300	$77,500	$85,500

Question 5b: Actual and estimated staffing levels.

Answer: Staffing Level (FTE)	419	416	414

HIGH ENERGY PHYSICS

Question 5c: Actual and estimated utilization of the facility, and optimal level of utilization of the facility.

Answer: (In weeks of AGS operation)

Actual/estimated	14	20	16
Optimal*	31	31	31

*The optimal AGS utilization level is approximately 41 weeks per year. Assuming 10 weeks of operation is supported by the Nuclear Physics Program, then the optimal High Energy Physics utilization level would be 31 weeks.

With sufficient dollars a number of the facilities which the Department runs, including the AGS at Brookhaven National Laboratory, could be physically operated longer; however, choices have been made according to importance of the research. The department believes that this is an efficient and effective level of operation. The number of physical hours the facility could be operated would be 5,208 (31 weeks for HEP).

Question 5d: Level of funding required to achieve the optimal level of utilization of the facility.

Answer: Additional funding needed to fully support operations at the physical maximum. (B/A in thousands of dollars)

Actual FY 1987	Estimate FY 1988	Estimate FY 1989
$10,500	$10,800	$11,000

Question 5e: Additional research funding required to support the optimal level of utilization of the facility.

Answer: Additional research funding required by laboratory and University-based experimenters to support the physical maximum utilization. (B/A in thousands of dollars)

$ 2,000	$ 1,500	$ 2,000

HIGH ENERGY PHYSICS

Question 6: For FY 1987 - FY 1989, please provide the information requested in a. - e. below for the Fermi National Accelerator Laboratory.

a: Actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, capital equipment, general plant projects, accelerator improvement projects, and any other funding attributable to the facility. Please indicate the sources of the funds (i.e., High Energy Physics, Nuclear Physics, Basic Energy Sciences, etc.).

Answer: The following table indicates the requested budget profiles for

High Energy Physics funds (B/A in thousands of dollars):

	Actual FY 1987	Estimate FY 1988	Estimate FY 1989
Accelerator Operations	$103,179	$115,500	$125,700
In-house Research	10,286	8,135	8,400
Out-of-House Research	-0-	-0-	-0-
Other operating expenses (Technology R&D)	19,380	15,320	16,300
Total Operating Funds	$132,845	$138,955	$150,400
Capital Equipment	$ 27,500	$ 25,283	$ 30,800
Accelerator Improvement Projects	5,450	5,800	6,050
General Plant Projects	2,950	3,300	3,418
Central Computing Upgrade Project	7,000	11,000	3,632
Tevatron I	367	-0-	-0-
Total Construction	$ 15,767	$ 20,100	$ 13,100
Total Laboratory Funding	$ 176,112	$184,338	$194,300

Question 6b: Actual and estimated staffing levels.

Answer: Staffing Level (FTE Persons)	2,030	2,050	2,055

Question 6c: Actual and estimated utilization of the facility, and optimal level of utilization of the facility.

Answer:

Actual/Estimated	48 weeks	42 weeks	44 weeks
Optimal	48 weeks	42 weeks	44 weeks

HIGH ENERGY PHYSICS

(Question 6c continued)

With sufficient dollars a number of the facilities which the Department runs, including Tevatron at Fermilab, could be physically operated longer; however, choices have been made according to importance of the research. The department believes that this is an efficient and effective level of operation. The number of physical hours the facility could be operated would be 7,392 (44 weeks for HEP).

Question 6d: Level of funding required to achieve the optimal level of utilization of the facility.

Answer: Additional funding needed to fully support operations at the physical maximum. (B/A in thousands of dollars)

Actual FY 1987	Estimate FY 1988	Estimate FY 1989
$ 2,500	$ 5,000	$ 8,000

Although the level of Fermilab operation in weeks does not change substantially from FY 1988 to FY 1989, there is more fixed target operation in FY 1989, which is more expensive than collider operation. Furthermore, the budgets in FY 1987 and FY 1988 are marginal to sustain the levels of operation achieved. With the superconducting machine it is very disruptive to warm up the machine; since the machine must be kept cold even during down time there is little to be saved by not running. The laboratory, with DOE's concurrence, is giving highest priority to operating the Tevatron. To do this with a marginal budget places quite a strain on laboratory personnel, has resulted in significant drawing down of supplies and spare parts, and has required deferring maintenance. This mode of operation cannot be sustained for a long period without potentially serious reliability problems. The increase in the FY 1989 operating budget would address this problem and would permit more stable operation.

HIGH ENERGY PHYSICS

Question 6e: Additional research funding required to support the physical level of utilization of the facility.

Answer: Additional research funding required by laboratory and University-based experimenters to support the physical maximum utilization. (B/A in thousands of dollars).

$ 2,000	$ 1,500	$ 1,500

HIGH ENERGY PHYSICS

Question 7c: Actual and estimated utilization of the facility, and optimal level of utilization of the facility.

Answer: (In weeks of operation)

	Actual FY 1987	Estimate FY 1988	Estimate FY 1989
Accelerator Testing & Development	47	17	3
Optimum	(17)	(8)	(3)
SLC	0	13	31
Optimum	(15)	(22)	(37)
PEP	0	9	31
Optimum	(15)	(19)	(31)
SPEAR	0	9	19
Optimum	(15)	(19)	(24)

The optimum and actual weeks of operation shown above in FY 1987 and FY 1988 are substantially impacted by the construction and preoperational testing of the SLC project. No physics operations were planned or conducted during FY 1987; physics operations in FY 1988 are determined by the SLC start-up date and the inability to run SLC simultaneously with PEP and SPEAR. The SLC is expected to begin operation for physics in May FY 1988 and be available for extensive operation in FY 1989. It is also assumed that simultaneous operation of SPEAR and PEP with SLC will be possible in FY 1988.

With sufficient dollars a number of the facilities which the Department runs, including the SLC, PEP, and SPEAR at SLAC, could be physically operated longer; however, choices have been made according to importance of the research. The department believes that this is an efficient and effective level of operation. The number of physical hours the facility could be operated would be 6,216 (37 weeks for HEP).

HIGH ENERGY PHYSICS

Question 7: For FY 1987 - FY 1989, please provide the information requested in a. - e. below for the Stanford Linear Accelerator Center at Stanford University.

a: Actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, capital equipment, general plant projects, accelerator improvement projects, and any other funding attributable to the facility. Please indicate the sources of the funds (i.e., High Energy Physics, Nuclear Physics, Basic Energy Sciences, etc.).

Answer: The following table indicates the requested budget profiles in High Energy Physics funds (B/A in thousands of dollars):

	Actual FY 1987	Estimate FY 1988	Estimate FY 1989
Accelerator Operations	$63,900	$73,400	$85,700
In-house Research	10,020	10,780	11,380
Out-of-House Research	780	220	120
Other operating expenses (Technology R&D)	13,260	13,420	13,000
Total Operating	$87,960	$97,820	$110,200
Capital Equipment	$18,100	$18,000	$ 22,700
Accelerator Improvement Projects	$ 2,800	$ 3,200	$ 3,350
General Plant Projects	1,650	1,800	1,900
SLC	976	-0-	-0-
Total Construction	$ 5,426	$ 5,000	$ 5,250
Total Laboratory Funding	$111,486	$120,820	$138,150

Question 7b: Actual and estimated staffing levels.

Answer: Staffing Level (FTE)	1305	1260	1310

HIGH ENERGY PHYSICS

Question 7d: Level of funding required to achieve the optimal level of utilization of the facility.

Answer: Additional funding needed to fully support operations at the physical maximum. (B/A in thousands of dollars)

$11,300	$14,600	$23,600

The major elements contributing to the cost increase in FY 1989 are the increased cost of electric power and klystrons for the substantially increased weeks of SLC operation and the higher pulse rate during FY 1989, and the fact that operation of PEP and SPEAR is planned simultaneously with SLC.

Question 7e: Additional research funding required to support the optimal level of utilization of the facility.

Answer: Additional research funding required by laboratory and University-based experimenters to support the physical maximum utilization. (B/A in thousands of dollars)

$ 1,000	$1,500	$2,000

NUCLEAR PHYSICS

Question 1: The February 12, 1988, "Holifield Tables" indicate that the "A/S REQ" for FY 1989 for the Nuclear Physics Program totalled $294.5 million, including $194.3 million for operating expenses and $100.2 million for plant and capital equipment. According to these tables, the Department's FY 1989 request to OMB totalled $264.1 million, including $193.1 million for operating expenses and $71.0 million for plant and capital equipment.

a. What are the specific differences between these two budgets?

Answer: The following table indicates the changes from the Assistant Secretary's budget request to the OMB request:

Nuclear Physics Program
(Budget Authority in Thousands)

	FY 1989 A/S Request	FY 1989 Request to OMB	Change
Operating Expenses	$194,300	$193,100	($ 1,200)
Capital Equipment	18,500	18,500	0
Construction	81,700	52,500	(29,200)
Total	$294,500	$264,100	($30,400)

Operating Expenses:

- The $1,200,000 reduction in the request for Operating Expenses resulted in a reduction in facility operations, primarily at LAMPF, and the Tandem/AGS, a reduction in the level of experimentation throughout the program, and a reduced level of R&D for the Relativistic Heavy Ion Collider at BNL.

Plant and Capital Equipment:

- A $20,500,000 reduction (from $65,000,000 to $44,500,000) in the Continuous Electron Beam Accelerator Facility (CEBAF) construction project, resulting in a six month delay in construction completion and an increase in TEC from $255,000,000 to $265,000,000.

- A $300,000 reduction in Accelerator Improvements and Modifications required delaying the upgrade of some of the remote interface control equipment at the LAMPF facility.

- A $400,000 reduction in General Plant Projects, limited planned maintenance projects at the Lawrence Berkeley Laboratory.

- A $2,000,000 reduction for proposed start of a Relativistic Heavy Ion Collider (RHIC) project at the Brookhaven National Laboratory.

- A $6,000,000 reduction for proposed start of a High Duty Factor Upgrade at the MIT-Bates Linear Accelerator Center.

Question 1b: What, if any, differences exist between the Department's request to OMB and the budget submitted to Congress?

Answer: The following table indicates that there were no differences between the Department's request to OMB, and the budget submitted to Congress:

Nuclear Physics Program
(Budget Authority in Thousands)

	FY 1989 Request to OMB	FY 1989 Congressional Request	Change
Operating Expenses	$193,100	$193,100	$ 0
Capital Equipment	18,500	18,500	0
Construction	52,500	52,500	0
Total	$264,100	$264,100	$ 0

NUCLEAR PHYSICS

Question 2: Please identify all unobligated balances in the Nuclear Physics Program.

Answer: The Nuclear Physics Program had an unobligated balance of $44,356 at the end of FY 1987. This unobligated balance resulted from contract negotiations which were not completed as of the end of FY 1987. These contracts were subsequently awarded and the funds obligated in early FY 1988.

NUCLEAR PHYSICS

Question 3: The FY 1989 budget request for Nuclear Theory states that DOE plans to "Establish a major Theory Institute with participation of broadly based Nuclear Physics programs."

a: What is the nature of this Institute?

Answer: The Institute would be a recognized center for concentrated theoretical research on selected topics at the frontier of modern nuclear physics and for the stimulation for young scientists.

Question 3b: Will the Institute be laboratory-based or university-based?

Answer: The location of the Institute is not yet determined, but is expected to involve both university and national laboratory components.

Question 3c: Does DOE intend to hold a competitive selection process to establish the Institute?

Answer: Yes, the DOE intends to select from competing proposals .

Question 3d: Why is a major "Theory Institute" needed?

Answer: The Subcommittee on Nuclear Theory of the Nuclear Science Advisory Committee states in a forthcoming report "the broad intellectual opportunities of nuclear theory and the need to focus efforts to meet these challenges make the creation of one or more centers for nuclear theory timely and potentially effective."

Question 3e: What will such an Institute provide that cannot be provided by the current theory effort?

Answer: The nuclear physics theory community, and especially the younger physicists are widely dispersed in small groups at universities throughout the country. One major benefit of a Theory Institute would be to provide a focal point for seminars, work sessions, and summer studies to enable these university scientists to maintain effective forefront research.

NUCLEAR PHYSICS

Question 4: Please define the criteria used to define those facilities included in the Basic Research User Facilities - Nuclear Physics (BRUF-NP) appropriations account. Why, for example, are the Holifield Heavy Ion Research Facility at Oak Ridge National Laboratory, or ATLAS at Argonne National Laboratory, or the Bates Linear Accelerator Center at MIT not funded under this account, while the Los Alamos Meson Physics Facility, the Bevalac at Lawrence Berkeley Laboratory, and the Tandem/AGS at Brookhaven National Laboratory, are funded under this account.

Answer: Those facilities included in the Basic Research User Facilities - Nuclear Physics (BRUF-NP) appropriations account represent large multi-user national facilities in which the major scientific impetus is due to experiments from universities and other outside organizations.

NUCLEAR PHYSICS

Question 5: Since last year's budget authorization hearings, the construction end date for the Continuous Electron Beam Accelerator Facility (CEBAF) has slipped by 2 Quarters (from 2nd Quarter, FY 1993 to 4th Quarter, FY 1993), the total estimated construction cost has increased by $10.0 million (from $255.0 million to $265.0 million), and the total project cost has increased by $10.0 million (from $294.514 million to $304.514 million). What are the technical reasons for the schedule delay and the cost increases?

Answer: The schedule changes and cost increases are completely due to a slowdown because of the decrease in the FY 1989 construction request and the resulting changes in the remainder of the budget profile.

NUCLEAR PHYSICS

Question 6: The CEBAF construction data sheet accompanying the FY 1988 budget request projected an authorization request of $65.0 million for CEBAF construction in FY 1989. However, in the FY 1989 budget request, DOE is only requesting $44.5 million for CEBAF construction. What are the technical reasons for this reduced request?

Answer: The FY 1989 budget request for CEBAF construction funds was determined on the basis of budgetary constraints.

NUCLEAR PHYSICS

Question 7: For FY 1987 - FY 1989, please provide the information requested in a. - e. below for the ATLAS Facility at Argonne National Laboratory.

a: Actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, capital equipment, general plant projects, accelerator improvement projects, and any other funding attributable to the facility. Please indicate the source of the funds (i.e., Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).

Answer: The following table indicates the requested budget profiles in Nuclear Physics funds (B/A in thousands of dollars):

	FY 1987	FY 1988	FY 1989
Accelerator operations	$2,815	$2,790	$2,880
In-house research	4,135	4,420	4,560
Out-of-house research	100	100	100
Capital equipment	1,360	1,495	1,655
Accelerator improvement projects	950	1,500	1,500
General plant projects	0	0	0

Question 7b: Actual and estimated staffing levels.

Answer:

Staffing level (FTE)	65.9	61.5	60.3

Question 7c1: Actual and estimated utilization of the facility.

Answer:

Utilization (beam hours for research)	3,611	3,700	3,300

Question 7c2: Optimal level of utilization of the facility.

Answer: With sufficient dollars a number of the facilities which the Department runs, including the ATLAS Facility at Argonne National Laboratory, could be physically operated longer; however, choices have been made according to importance of the research. The Department believes that this is an efficient and effective level of operation. The number of physical hours the facility could be operated would be 4,500 hours.

Question 7d: Level of funding required to achieve the optimal level of utilization of the facility.

Answer: For FY 1989 the funding needed to achieve the physical maximum of utilization would be $3,640,000.

Question 7e: Additional research funding required to support the optimal level of utilization of the facility.

Answer: For FY 1989 the additional research funding required to fully support the operations at the physical maximum would be $570,000.

NUCLEAR PHYSICS

Question 8: For FY 1987 - FY 1989, please provide the information requested in a. - e. below for the Tandem/AGS Facility at Brookhaven National Laboratory.

a: Actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, capital equipment, general plant projects, accelerator improvement projects, and any other (funding attributable to the facility. Please indicate the source of the funds (i.e., Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).

Answer: The following table indicates the requested budget profiles in

Nuclear Physics funds (B/A in thousands of dollars):

	FY 1987	FY 1988	FY 1989
Accelerator operations	$6,980	$7,195	$7,710
In-house research	3,100	3,200	3,490
Out-of-house research	0	0	0
Capital equipment	3,730	3,830	4,200
Accelerator improvement projects	600	750	900
General plant projects	0	0	0

Question 8b: Actual and estimated staffing levels.

Answer:

Staffing level (FTE)	86.0	92.0	95.0

Question 8cl: Actual and estimated utilization of the facility.

Answer:

Utilization (beam hours for research)	650	700	750

Question 8c2: Optimal level of utilization of the facility.

Answer: With sufficient dollars a number of the facilities which the Department runs, including the Tandem/AGS Facility at Brookhaven National Laboratory, could be physically operated longer; however, choices have been made according to importance of the research. The Department believes that this is an efficient and effective level of operation. The number of physical hours the facility could be operated would be 850 hours.

Question 8d: Level of funding required to achieve the optimal level of utilization of the facility.

Answer: For FY 1989 the funding needed to achieve the physical maximum of utilization would be $8,840,000.

Question 8e: Additional research funding required to support the optimal level of utilization of the facility.

Answer: For FY 1989 the additional research funding required to fully support operations at the physical maximum would be $510,000.

NUCLEAR PHYSICS

Question 9: For FY 1987 - FY 1989, please provide the information requested in a. - e. below for the Bevalac Facility at the Lawrence Berkeley Laboratory.

a: Actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, capital equipment, general plant projects, accelerator improvement projects, and any other funding attributable to the facility. Please indicate the source of the funds (i.e., Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).

Answer: The following table indicates the requested budget profiles in

Nuclear Physics funds (B/A in thousands of dollars):

	FY 1987	FY 1988	FY 1989
Accelerator operations	$17,992	$18,037	$18,611
In-house research	3,795	3,932	4,050
Out-of-house research	1,694	1,847	1,902
Capital equipment	2,044	2,105	2,250
Accelerator improvement projects	720	850	400
General plant projects	0	0	0

Question 9b: Actual and estimated staffing levels.

Answer:

Staffing level (FTE)	189.0	181.0	179.0

Question 9c1: Actual and estimated utilization of the facility.

Answer:

Utilization (beam hours for research)	4,023	3,500	3,300

Question 9c2: Optimal level of utilization of the facility.

Answer: With sufficient dollars a number of the facilities which the Department runs, including the Bevalac Facility at the Lawrence Berkeley Laboratory, could be physically operated longer; however, choices have been made according to importance of the research. The Department believes that this is an efficient and effective level of operation. The number of physical hours the facility could be operated would be 4,500 hours.

Question 9d: Level of funding required to achieve the optimal level of utilization of the facility.

Answer: For FY 1989 the funding needed to achieve the physical maximum of utilization would be $20,790,000.

Question 9e: Additional research funding required to support the optimal level of utilization of the facility.

Answer: For FY 1989 the additional research funding required to fully support operations at the physical maximum would be $650,000.

NUCLEAR PHYSICS

Question 10: For FY 1987 - FY 1989, please provide the information requested in a. - e. below for the 88 Inch Cyclotron Facility at the Lawrence Berkeley Laboratory.

a: Actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, capital equipment, general plant projects, accelerator improvement projects, and any other funding attributable to the facility. Please indicate the source of the funds (i.e., Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).

Answer: The following table indicates the requested budget profiles in

Nuclear Physics funds (B/A in thousands of dollars):

	FY 1987	FY 1988	FY 1989
Accelerator operations	$2,033	$2,108	$2,185
In-house research	2,527	2,565	2,642
Out-of-house research	15	15	15
Capital equipment	333	299	350
Accelerator improvement projects	180	50	600
General plant projects	0	0	0

Question 10b: Actual and estimated staffing levels.

Answer:

Staffing level (FTE)	46.3	46.3	46.3

Question 10c1: Actual and estimated utilization of the facility.

Answer:

Utilization (beam hours for research)	4,234	4,100	4,100

Question 10c2: Optimal level of utilization of the facility.

Answer: With sufficient dollars a number of the facilities which the Department runs, including the 88 Inch Cyclotron at the Lawrence Berkeley Laboratory, could be physically operated longer; however, choices have been made according to importance of the research. The Department believes that this is an efficient and effective level of operation. The number of physical hours the facility could be operated would be 5,000 hours.

Question 10d: Level of funding required to achieve the optimal level of utilization of the facility.

Answer: For FY 1989 the funding needed to achieve the physical maximum of utilization would be $2,800,000.

Question 10e: Additional research funding required to support the optimal level of utilization of the facility.

Answer: For FY 1989 the additional research funding required to fully support operations at the physical maximum would be $508,000.

NUCLEAR PHYSICS

Question 11: For FY 1987 - FY 1989, please provide the information requested in a. - e. below for the Los Alamos Meson Physics Facility (LAMPF) at the Los Alamos National Laboratory.

a: Actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, capital equipment, general plant projects, accelerator improvement projects, and any other funding attributable to the facility. Please indicate the source of the funds (i.e., Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).

Answer: The following table indicates the requested budget profiles in

Nuclear Physics funds (B/A in thousands of dollars):

	FY 1987	FY 1988	FY 1989
Accelerator operations	$40,600	$41,325	$42,650
In-house research	5,126	5,267	5,369
Out-of-house research	1,210	1,238	1,231
Capital equipment	2,382	2,735	2,545
Accelerator improvement projects	1,400	500	400
General plant projects	850	700	500

Question 11b: Actual and estimated staffing levels.

Answer:

Staffing level (FTE)	288.0	275.0	274.0

Question 11c1: Actual and estimated utilization of the facility.

Answer:

Utilization (beam hours for research)	3,148	2,800	3,000

Question 11c2: Optimal level of utilization of the facility.

Answer: With sufficient dollars a number of the facilities which the Department runs, including the Los Alamos Meson Physics Facility (LAMPF) at the Los Alamos National Laboratory, could be physically operated longer; however, choices have been made according to importance of the research. The Department believes that this is an efficient and effective level of operation. The number of physical hours the facility could be operated would be 4,000 hours.

Question 11d: Level of funding required to achieve the optimal level of utilization of the facility.

Answer: For FY 1989 the funding needed to achieve the physical maximum of utilization would be $46,750,000.

Question 11e: Additional research funding required to support the optimal level of utilization of the facility.

Answer: For FY 1989 the additional research funding required to fully support operations at the physical maximum would be $601,000.

NUCLEAR PHYSICS

Question 12: For FY 1987 - FY 1989, please provide the information requested in a. - e. below for the Bates Linear Accelerator Center at the Massachusetts Institute of Technology.

a: Actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, capital equipment, general plant projects, accelerator improvement projects, and any other funding attributable to the facility. Please indicate the source of the funds (i.e., Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).

Answer: The following table indicates the requested budget profiles in Nuclear Physics funds (B/A in thousands of dollars):

	FY 1987	FY 1988	FY 1989
Accelerator operations	$5,950	$6,340	$6,350
In-house research	2,924	2,944	2,838
Out-of-house research	150	156	162
Capital equipment	1,095	1,150	1,150
Accelerator improvement projects	250	750	500
General plant projects	450	300	600

Question 12b: Actual and estimated staffing levels.

Answer:

Staffing level (FTE)	92.0	94.2	94.6

Question 12c1: Actual and estimated utilization of the facility.

Answer:

Utilization (beam hours for research)	3,370	3,200	2,000

Question 12c2: Optimal level of utilization of the facility.

Answer: With sufficient dollars a number of the facilities which the Department runs, including the Bates Linear Accelerator Center at the Massachusetts Institute of Technology, could be physically operated longer; however, choices have been made according to importance of the research. The Department believes that this is an efficient and effective level of operation. The number of physical hours the facility could be operated would be 4,500 hours.

Question 12d: Level of funding required to achieve the optimal level of utilization of the facility.

Answer: For FY 1989 the funding needed to achieve the physical maximum of utilization would be $8,650,000.

Question 12e: Additional research funding required to support the optimal level of utilization of the facility.

Answer: For FY 1989 the additional research funding required to fully support operations at the physical maximum would be $662,000.

NUCLEAR PHYSICS

Question 13: For FY 1987 - FY 1989, please provide the information requested in a. - e. below for the Holifield Heavy Ion Research Facility at the Oak Ridge National Laboratory.

a: Actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, capital equipment, general plant projects, accelerator improvement projects, and any other funding attributable to the facility. Please indicate the source of the funds (i.e., Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).

Answer: The following table indicates the requested budget profiles in

Nuclear Physics funds (B/A in thousands of dollars):

	FY 1987	FY 1988	FY 1989
Accelerator operations	$4,940	$4,960	$5,135
In-house research	2,942	2,787	2,985
Out-of-house research	943	1,193	1,140
Capital equipment	945	910	880
Accelerator improvement projects	0	0	0
General plant projects	0	0	0

Question 13b: Actual and estimated staffing levels.

Answer:

Staffing level (FTE)	73.5	75.1	73.3

Question 13c1: Actual and estimated utilization of the facility.

Answer:

Utilization (beam hours for research)	4,591	3,600	4,000

Question 13c2: Optimal level of utilization of the facility.

Answer: With sufficient dollars a number of the facilities which the Department runs, including the Holifield Heavy Ion Research Facility at the Oak Ridge National Laboratory, could be physically operated longer; however, choices have been made according to importance of the research. The Department believes that this is an efficient and effective level of operation. The number of physical hours the facility could be operated would be 5,000 hours.

Question 13d: Level of funding required to achieve the optimal level of utilization of the facility.

Answer: For FY 1989 the funding needed to achieve the physical maximum of utilization would be $6,050,000.

Question 13e: Additional research funding required to support the optimal level of utilization of the facility.

Answer: For FY 1989 the additional research funding required to fully support operations at the physical maximum would be $100,000.

NUCLEAR PHYSICS

Question 14: For FY 1987 - FY 1989, please provide the information requested in a. - e. below for the Triangle Universities Nuclear Laboratory at Duke University.

a: Actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, capital equipment, general plant projects, accelerator improvement projects, and any other funding attributable to the facility. Please indicate the source of the funds (i.e., Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).

Answer: The following table indicates the requested budget profiles in Nuclear Physics funds (B/A in thousands of dollars):

	FY 1987	FY 1988	FY 1989
Accelerator operations	$ 715	$ 735	$ 775
In-house research	1,168	1,177	1,195
Out-of-house research	32	80	110
Capital equipment	500	290	250
Accelerator improvement projects	0	0	0
General plant projects	0	0	0

Question 14b: Actual and estimated staffing levels.

Answer:

Staffing level (FTE)	67.0	64.0	67.0

Question 14c1: Actual and estimated utilization of the facility.

Answer:

Utilization (beam hours for research)	6,500	6,500	6,500

Question 14c2: Optimal level of utilization of the facility.

Answer: With sufficient dollars a number of the facilities which the Department runs, including the Triangle Universities Nuclear Laboratory at Duke University, could be physically operated longer; however, choices have been made according to importance of the research. The Department believes that this is an efficient and effective level of operation. The number of physical hours the facility could be operated would be 6,500 hours.

Question 14d: Level of funding required to achieve the optimal level of utilization of the facility.

Answer: For FY 1989 the funding needed to achieve the physical maximum of utilization remains at $775,000.

Question 14e: Additional research funding required to support the optimal level of utilization of the facility.

Answer: For FY 1989 the additional research funding required to fully support operations at the physical maximum would be $250,000.

NUCLEAR PHYSICS

Question 15: For FY 1987 - FY 1989, please provide the information requested in a. - e. below for the Tandem/Superconducting Booster Accelerator Facility at the University of Washington.

a: Actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, capital equipment, general plant projects, accelerator improvement projects, and any other funding attributable to the facility. Please indicate the source of the funds (i.e., Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).

Answer: The following table indicates the requested budget profiles in

Nuclear Physics funds (B/A in thousands of dollars):

	FY 1987	FY 1988	FY 1989
Accelerator operations	$ 800	$1,030	$1,060
In-house research	1,140	1,320	1,380
Out-of-house research	90	95	100
Capital equipment	0	100	250
Accelerator improvement projects	0	0	0
General plant projects	0	0	0

Question 15b: Actual and estimated staffing levels.

Answer:

Staffing level (FTE)	31.0	37.0	38.0

Question 15c1: Actual and estimated utilization of the facility.

Answer:

Utilization (beam hours for research)	2,600	3,000	3,600

Question 15c2: Optimal level of utilization of the facility.

Answer: With sufficient dollars a number of the facilities which the Department runs, including the Tandem/Superconducting Booster Accelerator Facility at the University of Washington, could be physically operated longer; however, choices have been made according to importance of the research. The Department believes that this is an efficient and effective level of operation. The number of physical hours the facility could be operated would be 4,500 hours.

Question 15d: Level of funding required to achieve the optimal level of utilization of the facility.

Answer: For FY 1989 the funding needed to achieve the physical maximum of utilization would be $1,335,000.

Question 15e: Additional research funding required to support the optimal level of utilization of the facility.

Answer: For FY 1989 the additional research funding required to fully support operations at the physical maximum would be $220,000.

NUCLEAR PHYSICS

Question 16: For FY 1989 - FY 1989, please provide the information requested in a. - e. below for the Tandem Van de Graaff Facility at Yale University.

a. Actual and estimated budget profiles for operations, in-house research, out-of-house research, other operating expenses, capital equipment, general plant projects, accelerator improvement projects, and any other funding attributable to the facility. Please indicate the source of the funds (i.e., Nuclear Physics, High Energy Physics, Basic Energy Sciences, etc.).

Answer: The following table indicates the requested budget profiles in Nuclear Physics funds (B/A in thousands of dollars):

	FY 1987	FY 1988	FY 1989
Accelerator operations	$1,295	$1,330	$1,375
In-house research	200	420	1,185
Out-of-house research	970	850	130
Capital equipment	0	290	250
Accelerator improvement projects	0	0	0
General plant projects	0	0	0

Question 16b: Actual and estimated staffing levels.

Answer:

Staffing level (FTE)	55.0	60.0	65.0

Question 16c1: Actual and estimated utilization of the facility.

Answer:

Utilization (beam hours for research)	under const.	4 mo. 1,000	4,500

Question 16c2: Optimal level of utilization of the facility.

Answer: With sufficient dollars a number of the facilities which the Department runs, including the Tandem Van de Graaff Facility at Yale University, could be physically operated longer; however, choices have been made according to importance of the research. The Department believes that this is an efficient and effective level of operation. The number of physical hours the facility could be operated would be 6,000 hours.

Question 16d: Level of funding required to achieve the optimal level of utilization of the facility.

Answer: For FY 1989 the funding needed to achieve the physical maximum of utilization would be $1,465,000.

Question 16e: Additional research funding required to support the optimal level of utilization of the facility.

Answer: For FY 1989 the additional research funding required to fully support operations at the physical maximum would be $195,000.

NUCLEAR PHYSICS

Question: There is great concern on the part of this Subcommittee that construction funding for the Continuous Electron Beam Accelerator Facility (CEBAF) is not sufficient to assure the completion without further cost escalation and schedule delays. The present budget request for CEBAF construction amounts to $44.5 million, about $20 million short of the amount needed in FY 1989.

> Why has the Department chosen not to pursue the timely completion of this project on schedule to avoid incurring significant escalations in the total project cost?

Answer: The construction funding for CEBAF has been determined by the Department taking into account the need for acceptable progress on the construction project balanced against operation and research of existing activities in a climate of budgetary constraints.

NUCLEAR PHYSICS

Question: One of the highest priorities in the deliberations of the Nuclear Science Advisory Committee has been the construction of the Relativistic Heavy Ion Collider (RHIC). No construction funds were asked for in the FY 1989 budget request. This is an essential facility, we understand, in order to sustain a strong U.S. program in heavy ion physics research.

Why has the Department not proposed construction funds for this project in FY 1989? Is this project of lower priority than other projects within the Office of Energy Research?

Answer: The Nuclear Science Advisory Committee (NSAC) 1983 Long Range Plan for Nuclear Science identified RHIC as "the highest priority for the next major facility to be constructed, with the potential of addressing a new scientific frontier of fundamental importance." That highest scientific priority has been reaffirmed by NSAC in 1984 and again in 1986. The technical readiness, costs, and schedules of the project have been reviewed by the DOE with the findng that the project would be ready to proceed. However, in these times of fiscal restraint, even some very high priority projects must be postponed.

HIGH ENERGY AND NUCLEAR PHYSICS

Question: How would you compare United States programs in nuclear physics and high energy physics relative to those of our international colleagues? It would seem that the budget levels we are applying to this program, we should still remain the world leader in these areas.

> **Has the Department initiated efforts to assure that strong cooperative programs with our international colleagues in high energy physics and nuclear physics are sufficiently well maintained?**

Answer: I would like to answer this question in two parts. First I would like to address the High Energy Physics Program, and second, the Nuclear Physics Program.

High Energy Physics

The U.S. High Energy Physics (HEP) program continues to maintain a world leadership position relative to other regions. In his address to the Department of Energy High Energy Physics Advisory Panel (HEPAP) on March 1, 1988, Professor Carlo Rubbia, Nobel Laureate and Director Designate of CERN issued some warning signals. His comparison of funding showed that Europe (comprised of the 14 CERN Member states) devotes 50% more resources to HEP relative to its GNP than does the U.S. If the Superconducting Supercollider (SSC) is funded, the U.S. would be in approximate spending parity with Europe, but only during the years of construction. The addition of the SSC to the panoply of world accelerator facilities will represent a strong step into the future which would guarantee a position of world leadership for the U.S. well into the turn of the century. These sentiments were echoed in the Testimony of Professor Francis E. Low, Chairman of HEPAP in his appearance before HSST on March 30, 1988.

Currently U.S. facilities are in general complementary to those in other regions of the world, enabling considerable mutual collaborative use of facilities. This use is based on internationally agreed-upon guidelines that emphasize open, international access based on scientific merit of the proposed research. While most of the international collaborations for research in HEP are established directly among participating institutions, formal intergovermental arrangements have been established with Japan, the Peoples Republic of China, the U.S.S.R., and Spain. Thus we have extensive international collaborative efforts for experimentalists in high energy physics both at U.S. facilities and at facilities abroad. In the U.S. they include teams of scientists from Japan, France, Italy, Canada, the Soviet Union, and other teams. Abroad, there are strong U.S. teams working at almost every major facility.

Nuclear Physics

Answer: As part of the process for preparation of "The Long Range Plan for Nuclear Science" of December 1983, NSAC compared the support levels of basic nuclear physics research between the United States and other advanced countries which provide most of the non-communist world physics support. They found that these eight countries (western Europe and Canada) provided 80% more support than the U.S. in actual dollars; on the basis of GNP the ratio was 2.3 to one. This rather depressing set of statistics suggests that the U.S. program should inexorably be losing ground to the rest of the world. The discrepancy between funding levels appears to be most evident in the area of instrumentation.

Nevertheless, the U.S. program is of high quality and competitive in most areas of nuclear physics and provides world leadership in the forefront specialties. The ability to compete has been maintained by judicious choice of projects and scientific areas for emphasis. Areas in which the U.S. sets the pace are in intermediate energy hadronic physics, electromagnetic physics, and in high energy and relativistic heavy ion physics. Completion of the CEBAF facility using the advanced superconducting radiofrequency cavity technology, and the MIT South Hall Ring and Brookhaven Laser Electron Gamma Source (LEGS) experiments will maintain our leadership role in electromagnetic physics. Construction of the proposed Relativistic Heavy Ion Collider facility at Brookhaven National Laboratory will continue the U.S. program at the forefront of relativistic heavy ion physics well into the 21st century. At a smaller scale, improvements to the ATLAS facility at Argonne National Laboratory will provide the world's only source of continuous uranium beams at Coulomb barrier energies. Rapid implementation of selected major detector projects is equally important for maintaining international competitiveness. Implementation of a Nuclear Theory Institute will help provide the focus for concentration of our research efforts at the frontiers of modern nuclear physics.

Nuclear scientists continue to attack the forefront research problems using the most effective facility independent of location. Substantial personnel and equipment funding has been provided by Japan for heavy ion physics research at Brookhaven National Laboratory and Lawrence Berkeley Laboratory, from Italy for the LEGS project at Brookhaven National Laboratory, and from West Germany for experiments at several laboratories. Significant U.S. efforts have gone into use of the LEAR antiproton ring at CERN, for the positron production experiment at GSI in West Germany, and for use of the relativistic ion beams at CERN. Continuing strong efforts continue at the GANIL facility and the ILL nuclear reactor in France, at the VEPP-3 electron storage ring in the USSR, at the NIKHEF electron facility in the Netherlands, and at several other facilities. The activity remains high and in overall balance in the international exchanges of individual scientists and research groups between the United States and the rest of the world. As a major benefit, the U.S. programs continue to attract students and young scientists to the strong research groups and facilities in this country.

PANEL 1: DEPARTMENT OF ENERGY— [illegible] ENERGY PHYSICS ADVISORY PANEL AND NUCLEAR SCIEN[illegible]VISORY COMMIT[illegible]E

Mr. CHAPMAN. I would like the next [illegible] Dr. Francis E. Low, Chairman of the High Energy Physics [illegible]ry Panel; Dr. Ernest M. Henley, Chairman of the Nuclear S[illegible] Advisory Panel. We welcome you gentlemen this morning. I[illegible] you all have changed the signs or changed the seats. Are you [illegible] to confuse us simple-minded people up here? Welcome, gentl[illegible] we are pleased that you are with us today.

Dr. Henley, at this point I would like [illegible] proceed in your own fashion and summarize if you can your [illegible]ents. Of course, your full statements will be made a part of [illegible]rd.

STATEMENT OF DR. ERNEST M. HENL[illegible]ROFESSOR OF PHYSICS, UNIVERSITY OF WASHINGTON, [illegible]LE, WA, AND CHAIRMAN, DOE/NSF NUCLEAR SCIENCES [illegible]ORY COMMITTEE

Dr. HENLEY. Thank you. Mr. Chairm[illegible]mbers of the Subcommittee, I am Ernest Henley, chairman [illegible]Nuclear Science Advisory Committee, and I thank you for t[illegible]ortunity to testify on the status, plans and aspirations of nuc[illegible]ysics and its community of scientists.

As you know, the Nuclear Science A[illegible]y Committee which I chair is selected by the Department [illegible]rgy and the National Science Foundation to provide advice [illegible]he management and long-range planning of the national p[illegible] of basic nuclear research. We have provided the agencies [illegible] a long-range plan as long as five years ago, but that plan ha[illegible] reviewed in 1984 and its major elements are still only begin[illegible] be put into effect, so that the plan remains viable.

The key elements of that plan are [illegible]ws. The first priority for major construction should be the [illegible] electron accelerator now being constructed at CEBAF. Clea[illegible] Nuclear Science Advisory Committee not only supports b[illegible]es the timely completion of that project.

The next major construction projec[illegible]ld be the Relativistic Heavy Ion Collider (RHIC), the facility [illegible]ich is viewed as complementary to that of the electron ac[illegible]tor. If developed in a timely fashion, this facility, which is n[illegible]ively being planned at Brookhaven National Laboratory, wil[illegible]de the United States with a unique facility which will all[illegible] to explore dynamics under extreme conditions. These condi[illegible]re expected to lead to a new phase of matter, namely quark-[illegible]lasma, which is related to the understanding of the beginni[illegible]ur universe.

It is our hope on the Nuclear Science [illegible]sory Committee, and it includes me, that the timely completion [illegible]BAF will soon permit the possibility of beginning actual co[illegible]ion of the Relativistic Heavy Ion Collider.

In addition, the long-range plan str[illegible]he importance of adequate support for the continuing base [illegible]am in nuclear science with the existing facilities. This has b[illegible]nd remains, an important concern of the Nuclear Science [illegible]ry Committee, as well as the nuclear physics community. It [illegible]y with a vigorous program of research at universities and [illegible]nal Laboratories that new, innovative ideas will develop and that a new generation of scientists, important not only to the new facilities but also to our society as well as to the future of our field, will receive appropriate training. In that regard, we are most pleased that the MIT Bates Laboratory upgrade is in the President's budget as recommended by the Nuclear Science Advisory Committee.

During the past year, the Nuclear Science Advisory Committee examined some of the critical issues which face our field. It is perhaps not surprising that most of them concern money. The committee has been concerned with issues that include statistics on the number of persons in the field, inflation, and the needs and opportunities to strengthen nuclear theory.

On the first issue of manpower statistics, we have sought a simple manner of gathering meaningful annual information about persons in our field.

The Inflation Subcommittee of the Nuclear Science Advisory Committee reported last month on a study of 20 nuclear science groups and laboratories. For the period of 1981 to 1987, they found that even excluding indirect costs, which also have increased at a rapid rate, and the cost of increased sophistication of carrying out experiments, the true average increase in unit cost was more than twice the Consumer Price Index, which is used by the Office of Management and Budget. Although the results are not surprising to many of us in the field, it shows that the problems faced by the community in trying to carry out forefront research with a lack of sufficient operating support. I believe that one of the major problems is that salaries, tuitions and fees at universities have risen faster than inflation, perhaps because these costs did not keep pace with inflation during an earlier period of time.

Although the Theory Subcommittee has not yet delivered its final report, it made an interim presentation at a recent meeting and made it clear that more theoretical nuclear physicists are required to keep up with new advances in the field and with opportunities which have been opened already by new facilities and which are likely to continue to be opened by the facilities which will be coming on line soon—we hope. Indeed, the fraction of nuclear theorists compared to their experimental colleagues is among the lowest of any fields in physics.

In answer to your request for critical issues, the community continues to be concerned about the CPI-indexed inflationary increase in operations support over the past years, which has meant a decrease in terms of actual money available for carrying out experiments.

In addition, the community would clearly like to see the timely completion of CEBAF so that structure physics made possible by that facility can be explored as rapidly and in as timely a fashion as possible and so that construction for RHIC may begin as soon as possible.

Both of these facilities will be unique, but laboratories in other countries are trying to reach conditions which approach the capability of these facilities. For instance, at CERN in Geneva, an international laboratory, they are planning a new heavy-ion injector which would allow lead nuclei, among the heaviest nuclei known, to be injected and accelerated to 180-GeV per nucleon. Although this does not really approach the facilities, the capability of the planned Relativistic Heavy Ion Collider, it is clearly a facility which is likely to be ready much earlier. However, it is also our view that it would be foolish to complete these new facilities at the expense of the ongoing research program, since it is at these facilities that future scientists, who will be required by the new facility to receive their training.

In light of those comments, I would like to make some remarks about the budget for nuclear science submitted to you by the President. The President's proposed budget has in it increases for the construction of CEBAF and for capital equipment. Both of these are necessary, but could usefully be larger. In particular, for instance, it would be nice to see CEBAF completed on the planned timetable rather than the delay which will be caused by the proposed budget.

For the operations budget, DOE's stated goal of retention of vigor in scientific and technological R&D to prepare for the future is extremely important. It will not be easy to accomplish with only a 4-percent slated increase, because as I have already indicated, true inflation in nuclear physics research runs almost at twice that figure.

I support the DOE proposal to fund a nuclear theory institute, but this also would require additional funds because the operating expenses for nuclear theory in the President's budget are only increased by one-half million dollars, which is insufficient in our view to begin this new proposal.

I stated to you last year also that it is the balance between the important need for new facilities and the ongoing research which is indeed a delicate one. I believe that the ongoing program requires more than the CPI-indexed inflationary increase in its operations budget.

Lastly, I would simply, in passing, make a few comments about some of the accomplishments which have been made in the field of nuclear physics. The details are in the written testimony, and I am only going to skim over them.

In particular, nuclear scientists have investigated nuclei under extremes of conditions both in rotational energy densities and in temperature. It is found that very stable shapes are found—for instance, so-called super-deformed nuclei—under some of these conditions. Furthermore, in Geneva at CERN, again, and both there and at Brookhaven, scientists have been able to show that high densities will indeed be able to reach at the Relativistic Heavy Ion Collider. At CERN, for instance, the estimate is that almost seven times nuclear densities have already been achieved. There are other hints that the conditions necessary for a phase transition can be reached, such as the decrease in the production of charmed particles.

At much lower energies, a new collective mode of motion has been found, a so-called scissors magnetic dipole mode.

Perhaps most important and among the more fundamental advances made during the past year has been the laboratory discovery of double beta decay. This is an extremely rare decay which has never been seen and is a second order weak interaction. That is, it is doubly weak. It is thus extremely rare, with a lifetime for the decay which has been seen of 10^{20} years. One of the reasons it is important is that it gives an indication of how much more difficult it will be to find the even rarer decay of second-order weak interaction without any neutrinos, which is being avidly sought.

At pion factories, in particular, an explanation of double charge exchange, which has been missing for quite some time, has been not only found but also shows the importance of nucleon-nucleon correlations which have been avidly sought for many years.

Lastly, in nuclear astrophysics a scenario has been proposed which may help to explain the abundance of the elements. In particular, fluctuations in the plasma created by the big-bang may contain neutron-rich regions which would allow nucleosynthesis of elements of the observed abundance.

In addition, nuclear physicists, like our colleagues in particle physics and in astrophysics have made important contributions to our understanding of the Supernova 1987 through neutrino astronomy and models of this and other supernovae.

Thank you again for the opportunity to testify. If I can answer questions or be of other assistance, I will be happy to do so.

[The prepared statement of Dr. Henley follows:]

March 30, 1988

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

Statement by Ernest M. Henley, University of Washington
Chairman, DOE/NSF
Nuclear Science Advisory Committee

Madame Chairman, Members of the Subcommittee:

Thank you for the opportunity to testify on the status, plans, and aspirations of nuclear physics and its community of scientists in connection with the DOE budget hearings.

THE NUCLEAR SCIENCE ADVISORY COMMITTEE AND ITS ACTIVITIES

The Nuclear Science Advisory committee, which I chair, is selected by the DOE and NSF to provide advice on the management and long-range planning of the national program of basic nuclear research.

The Nuclear Science Advisory Committee provided the agencies with a long-range plan in 1983. This plan was reviewed and reaffirmed in 1984. Its major elements still are only beginning to be put into effect and the plan remains valid. The key elements of that plan are as follows:

1) The first priority major construction project for nuclear physics should be a 4-GeV electron accelerator. Such a facility is now under construction at Newport News and will provide the U.S. with world-leading capabilities of exploring nuclear and subnuclear (quarks, gluons) structure. Clearly the Nuclear Science Advisory Committee not only supports, but urges, the timely construction of CEBAF.

2) The next major construction project should be a relativistic heavy ion collider (RHIC), a facility viewed as complementary to the electron accelerator. If developed in a timely fashion, this facility, now being actively planned at the Brookhaven National Laboratory, will provide the U.S. with a unique facility to explore nuclear dynamics under extreme conditions. These conditions are expected to lead to a new phase of matter, namely a quark-gluon plasma, which is related to the understanding of the beginning of our universe. It is the hope of the Nuclear Science Advisory Committee and myself that the timely completion of CEBAF will soon permit the possibility of beginning construction of RHIC.

3) In addition, the Long-Range Plan stressed the importance of adequate support for a continuing base program in nuclear science with existing facilities. This has been, and remains an important concern of the Nuclear Science Advisory Committee and the community. It is only with a vigorous program of research at universities and national laboratories, that new innovative ideas will develop and that new generations of scientists, so important to society, to the success of the new facilities, and to the future of the field, will receive appropriate training.

The Nuclear Science Advisory Committee has examined some of the critical issues which face our field. It is perhaps not surprising that most of them concern money. Thus the Committee has been concerned with issues that include statistics on persons in the field, inflation, and the needs and opportunities to strengthen nuclear theory.

On the first issue of manpower statistics, the NSAC has sought a simple manner of gathering meaningful annual information about persons in our field of physics.

The inflation subcommittee of the NSAC reported last month on a study of 20 nuclear science groups and laboratories. For the period of 1981-87, they found that, even excluding indirect costs and the cost of increased sophistication of carrying out experiments, the true average increase in unit costs was more than twice the Consumer Price Index used by the Office of Management and Budget. Although the results are not surprising to many of us in the field, this study shows the problems faced by the community of physicists in trying to carry out forefront research work with a lack of sufficient operations support. The major problem is that salaries, and tuition and fees at universities, have risen faster than inflation, perhaps because these costs did not keep up with inflation for a long earlier period of time.

The Theory Subcommittee has not yet delivered its final report, but the interim presentation by its chairman, Steven Koonin of the California Institute of Technology, makes it clear that more theoretical nuclear physicists are required to keep up with new advances, and with opportunities opened by the facilities which will be coming on line. Indeed, the fraction of nuclear theorists relative to their experimental colleagues is among the lowest of any field of physics.

CRITICAL ISSUES AND THE DOE BUDGET

In answer to your request for critical issues, the community continues to be concerned that the small CPI-indexed inflationary increase in operations support over the past years meant a decrease in terms of actual costs. In addition, the community would like to see the rapid completion of CEBAF so that the structure physics made possible by this facility can be fully exploited, and so that RHIC can get a timely start. Both of these facilities will be unique, but laboratories in other countries are trying to reach conditions which approach the capabilities of these two facilities. For instance, CERN (Geneva) is planning a new heavy ion injector which would allow lead nuclei to be accelerated to 180 GeV/nucleon. Although this is only about 1/10th of RHIC's planned capability, it is likely to be ready much earlier. However, we believe that it would be foolish to complete these facilities at the expense of the ongoing research program, since it is here that future scientists, required by the new facilities, are trained.

In light of the above remarks and activities, I would like to comment directly on the budget for nuclear science submitted to you. The President's proposed budget has in it increases for the construction of CEBAF and for capital equipment. Both of these are necessary but could usefully be larger. For the operations budget, DOE's stated goal of vigor retention in scientific and technological R & D to prepare for the future is important, but will not be easy to accomplish with only a 4% increase, because inflation in nuclear physics research runs higher. I support the DOE proposal to fund a Nuclear Theory Institute, but this would require additional funds, because the operating expenses for nuclear theory are only increased by 0.5 M in the President's budget, which is insufficient to begin this new proposal.

As I stated to you last year, the balance between the important need for new facilities and the ongoing research program is a delicate one. I believe that the ongoing program requires more than the Consumer Price Indexed inflationary increase in its operations budget.

SOME RECENT ACCOMPLISHMENTS IN NUCLEAR PHYSICS

Lastly, I would like to acquaint you with only a few of some of the recent accomplishments in the field of nuclear physics.

1) As a prelude to research to be carried out at a RHIC, nuclear physicists are exploring the behavior of nuclei under extreme conditions of density and temperature. Thus "hot" nuclei formed in heavy-ion fusion reactions show that the deformations remain unchanged at low spins for nuclei which already are deformed at low energies. On the other hand, spherical nuclei show a tendency for strong shape fluctuations when they become "hot."

At high spins, i.e. for very rapidly rotating, but cold nuclei, very elongated superdeformed shapes have been observed, with a major to minor axes ratio of 2 to 1. These superdeformed bands are formed in heavy ion collisions, with angular momenta up to $60\hbar$, for instance in the mass 152 region. Furthermore there are indications of shape changes from prolate (cigar-shaped) to oblate (pancake-like) with deexcitation.

Finally, experiments at CERN (Geneva) and at Brookhaven show that high densities can indeed be reached in heavy ion collisions. The estimate is that about seven times nuclear densities have been achieved at CERN. There are other hints that the conditions are on their way to the expected phase transition to a quark-gluon plasma. For instance, there is an expected decrease in the production of charm (ψ/J).

2) At much lower energies a new mode of nuclear collective motion, a "scissors" mode has been discovered. It is a magnetic dipole mode with neutrons vibrating against protons in a nucleus. In heavy deformed nuclei with an even number of neutrons and protons, the excitation energy of this mode is at about 3 MeV, and it is observed most easily with electrons.

3) One of the major fundamental advances made during the past year has been the laboratory discovery of the exceedingly rare double beta decay of ^{82}Se with the emission of two neutrinos. This is a second order weak interaction. It is thus exceedingly rare, with a very long lifetime of the order of 10^{20} years. Physicists have, for many years, struggled to observe this rare phenomenon directly. Although there had been indirect geochemical evidence for the presence of this very rare decay, it had never been observed directly. Its discovery in the laboratory, with the observation of both electrons emitted in the decay, is a triumph of experimental ingenuity.

The observation of this decay sets a benchmark for an even rarer decay, that of double beta decay without neutrinos. Thus it provides a reliable guide for the nuclear physics part of this even rarer decay. We now know how hard it is to look for the neutrinoless case, which tests our most fundamental understanding of nature, namely whether neutrinos are massless or have a very small mass. At present, we only know that the mass of the electron neutrinos is smaller than about 10-20 eV/c^2, where c is the velocity of light. This is about 35,000 times lighter than an electron.

4) At pion factories the pion double charge exchange process is a unique reaction where an incoming π^+ leaves the nucleus as a π^-. There is thus a change of charge of 2 units. The primary interest is in reactions which are quasi-elastic, in that they can leave the final nucleus in a so-called analogue state, one which is like the initial one except for the replacement of two neutrons by two protons. The observed cross sections are small, but have led to many puzzles. During the past year, a simple explanation of many of these puzzles appeared. The explanation, furthermore, involves an effect which has long been sought, namely nucleon-nucleon correlations. The inclusion of correlated nucleon modes, together with the uncorrelated two step process and the Pauli exclusion principle leads to an interference which can explain the experimental findings. It is interesting that it had been hoped that the double charge exchange reaction would allow one to study nucleon correlations. The unexpected feature is that they are found at much lower pion energies than anticipated.

5) Lastly in nuclear astrophysics, a scenario has been proposed which may help to explain the abundance of elements. Specifically, fluctuations in the plasma created by the big-bang may contain neutron rich regions, in which nucleosynthesis could give rise to the observed abundance. Potentially, this proposal may be able to solve the "missing mass" problem.

In addition nuclear physicists made important contributions to our understanding of supernova 1987A through neutrino astronomy and models of this and other supernovae.

Thank you again for the opportunity to testify. If the Nuclear Science Advisory Committee or I can be of assistance to you, I hope you will let me know.

Mr. **Chapman**. Thank you, Dr. Henley.

Let's proceed now with Dr. Low.

STATEMENT OF DR. FRANCIS E. LOW, PROFESSOR OF PHYSICS, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, CAMBRIDGE, MA, AND CHAIRMAN, DOE HIGH ENERGY PHYSICS ADVISORY PANEL

Dr. Low. Thank you, Mr. Chairman.

I am Francis Low. I am a theoretical physicist, professor and former provost at the Massachusetts Institute of Technology, and at present I am Chairman of the High Energy Physics Advisory Panel of the Department of Energy, and of course that is why I am here. Thank you for the opportunity to talk to you.

I should say that I have not discussed in any systematic way this testimony with the other members of the High Energy Physics Advisory Panel, so that what you will be hearing will be my views. I believe that the community on the whole is in agreement on these things, and I think I will speak for them and for the Panel, but it has not been in any formal way.

I would like in my comments to emphasize some of the points that I made in my written testimony. These will concern the base program, that is, everything except the Super Collider; the Super Collider itself; I want to make comments on the university program; and a few comments on the European program, that is, the program in high energy physics funded by the CERN member states.

With respect to the base program, for the last five to eight years we have been in a mode of preparing for a run of major experiments at SLAC, Fermilab, in Europe and in Japan, and that preparation is about to come to fruition. It is essential that that program be carried out, and I think Mr. Morrison's comment was very relevant. It is very difficult at any time to choose between a mode of preparing for the future and running with what you have got.

We have been in the first mode for the past few years, and it is really time to go into the second mode now. So I think that is the first priority. I agree with Dr. Decker on that.

These experiments will probe the limits of the present energy available in the world. They will give the final or almost final word on that energy domain, and they will prepare us for moving into the next energy domain with the Superconducting Super Collider.

By the time the Super Collider is built, the major part of the present program, I believe, will have been completed and there will be a large shift of resources, of people and of money from the base program into the Super Collider program. That will happen automatically in terms of what is available.

On the Superconducting Super Collider, the present uncertainty is damaging to the project itself, and it is also damaging to the High Energy Physics program in terms of the way people think about things and how they organize their lives and projects for the future. What is needed first is Congressional authorization, and most important is the need for a management structure, that is, a contractor and a director, which you did ask about, Mr. Chapman. I think it is very important.

For example, in order to negotiate reasonably with the international community, we have to have somebody who can speak for the project, who knows what is needed, who can say you build this and so on. Very important.

Then, of course, sufficient funding is needed to continue appropriately the research and development that is going on, and I think that the $80 million, 64 plus 16, in the present budget is a good figure for that.

Also it would be good to have, in addition to authorization, funding for long-lead time construction items, which are non-site specific since we haven't chosen the site yet.

Finally, I would like to comment on a situation which appears to be very damaging to the project. That is that the $8 million needed for the site search has to come out, apparently, of the $25 million R&D funds for the project in fiscal 1988, this year. If that really happens, I believe it will amount to closing down the project because there is just enough money in the project now to close it down if that is the final word, the total sum for the year, 25 minus 8.

So there is a very critical situation, and I hope something can be done about it.

I now want to turn to the university program. I do want to make some comments on that, although I didn't have any in my written statement. The funding for the university program is way out of proportion to the importance of that program to the high energy efforts. Funding is about $85 million out of $560 million in 1988, and that does not correspond in any way to the importance of the program.

It is an appropriate funding division for the Department because, of course, the Department spends most of its money supporting the major laboratories and facilities which make the research possible, and that is quite appropriate. But the major part of the leadership and the actual research in the program is done by people from the universities, university scientists. That means professors, post-doctoral fellows, graduate students and staff. The university participation is the heart of the program.

In addition, of course, that is where it contributes to education, the most important part of it, and that is where the cross-fertilization and communication of high energy physicists with other scientists and engineers, and even, not so occasionally, perhaps humanists takes place. I think I can't over-emphasize the importance of that.

If the university participation were to end, it would substantially effectively end the program. That is, the program would deteriorate enormously in value. So I second strongly Dr. Decker's response to your question about the National Science Foundation. It supports one-third of that program. That program is the heart of the high energy effort, and it will be very damaging if that support disappears.

Finally I want to say a few words about the program funded by the CERN member states, the European program. They are funded about two to one compared to our program referred to the gross national product of the areas. Not only are they funded twice as well;

they make very good use of that funding. The European program is first rate and they are very strong.

That is not all bad. We participate in the European program. We have a major part in many of the important experiments going on there. We are interested in their results. We are pleased that they are doing well and we like to see progress in high energy physics in Europe. Nevertheless, there is a competitive situation and it is a hard one to sustain with that funding ratio.

Thank you. That concludes my remarks. I will be happy to respond to questions.

[The prepared statement of Dr. Low follows:]

Testimony of Francis E. Low
to the Subcommittee on Energy Research and Development of the House Committee on Science, Space and Technology

March 30, 1988

My name is Francis Low. I am a theoretical physicist, Professor of Physics and former Provost at the Massachusetts Institute of Technology. I am currently serving as chairman of the Department of Energy's High Energy Physics Advisory Panel. Thank you for asking me to testify.

I. Major Issues

I would like to begin by very briefly summarizing my views on the major issues facing the high energy program. They will be discussed in more detail below.

1. Three steps are of fundamental importance to the successful development of the Superconducting Super Collider:
    - i. Increase of the Research and Development and Equipment programs to the $80M level requested by the President.
    - ii. Removal of the present uncertainty surrounding the program by Congressional Construction Authorization with sufficient funding to permit engineering development by industry.
    - iii. Creation of a management structure and appointment of a director.

2. The Base Program (all High Energy Physics except the SSC, including the University program) funding should be maintained at a level which permits full exploitation of the new front line facilities and detectors which we have been preparing for the last five or six years.

3. International (non U.S.) programs, especially in Geneva and Hamburg, are very strong, and are generously funded compared to the US program. We will have to work hard to remain competitive.

II. The State of Elementary Particle Physics

We are at a special time. Almost eighty years after the discovery of the nucleus we have a theory - called the Standard Model - which we believe can account for atomic, nuclear and subnuclear phenomena and which is crucial to our understanding of the cosmology of the early universe. The theory holds down to sizes which are thousands of times smaller than the nucleus (itself ten thousand times smaller than the atom). It includes the electromagnetic interactions, which bind electrons to the nuclei to form atoms; the weak interactions, responsible for radioactive decay; and the strong interactions, which bind quarks and gluons together to form nucleons and other heavy particles. As we come to even smaller sizes we don't know whether the same theory holds, but we have reason to suspect that a whole new world awaits discovery.

Fifty years ago was a comparable time. The discovery of quantum mechanics had just clarified the atomic domain, and had led to the union of chemistry and physics, and to all the new sciences and technologies that are based on our understanding of atoms and molecules. The nuclei remained mysterious: tiny and inert, they were clearly the next frontier. In the years since then, that frontier has been removed, and its mystery largely clarified. It is a remarkable success story. The understanding we now have is more than I expected to see in my lifetime.

Fifty years ago it was clear whe [illegible] next frontier lay: the nuclei. Today, analogously, it [illegible] ear where the next frontier lies: it lies where the [illegible] ty of the Standard Model may end, at sizes as small [illegible] ten thousandth of the size of the nucleon. It is [illegible] frontier that the Superconducting Super Collider is in [illegible] to probe.

Why must we explore the unknown [illegible] d that lies beyond this frontier? First, as Mallory s [illegible] ecause it's there. It's the next question in the histo [illegible] ne of enquiry that has probed smaller and smaller di [illegible] in the search for the constituents of matter. We want [illegible] ow what things can exist in our world; indeed, in [illegible] past, every major increase in accelerator energy, li [illegible] e one we are now contemplating at the SSC, has [illegible] d a host of new phenomena. Second, this line of [illegible] y -- studying what matter is made of in the most fund [illegible] l sense and how it works, starting with the work of [illegible] and Hooke in the seventeenth century -- is central [illegible] all science, both because it has consistently sp [illegible] f new scientific disciplines and new technologies, [illegible] because, by asking questions at the frontier, it [illegible] vers links between disciplines studying apparently un [illegible] d phenomena. The most recent example is the app [illegible] ion of elementary particle theory to the cosmology [illegible] the early universe. Third, within our present theory, [illegible] andard Model, there is a set of unanswered questions. T [illegible] del itself tells us that we will find some answers at th [illegible] el of energy probed by the SSC. Thus, we will know [illegible] why things are the way they are.

Like all basic science, high [illegible] gy physics is an investment in the future. It is an [illegible] tment in education, because it inspires and stimulates [illegible] ung people with the best minds to creative activity. [illegible] an investment which will help keep applied science and [illegible] ology alive because of their symbiosis with basic scie [illegible] It is part of the root system which supports the tre [illegible] echnology, not just by direct application, but also by creating the cultural environment in which all science can flourish. It is also an investment which may repay us many times over, as history teaches. Here it is important to understand that no one can forsee the basic scientific breakthroughs that will create major new technologies, or in which field of science they will come. Even high energy physics - although it appears unlikely - may some day startle us with an application. In 1933 Rutherford said "anyone who looked for a source of power from the transformation of the atoms was talking moonshine." Nine years later the first chain reaction took place in Chicago.

Finally, I mention technological spin-off. This occurs for many reasons, but often because in high energy physics existing technology is inadequate for performing an experiment or building an accelerator, so that new technologies have to be invented.

III. Issues raised in Mrs. Lloyd's letter of February 16.

1. The adequacy of planned activities in high energy physics:

I would like to discuss separately the base program (i.e. everything but the Super Collider) and the Super Collider. *I believe the funding proposed in the President's Budget for the base program is adequate, but will require that hard choices be made.* There are very high quality ongoing and planned U.S. programs at Brookhaven, Fermilab, SLAC, in Europe at CERN and DESY, and in Japan at KEK. These programs are exploring the energy domain where we expect the Standard Model to hold. There are still missing elements in the model and these elements may be uncovered by this

At CERN, in Geneva, the proton-anti proton collider, the $Sp\bar{p}S$, has been upgraded by a factor of ten in luminosity. This means that the same experiment can be done in one tenth the time, or with higher accuracy in the same time. (The $Sp\bar{p}S$ is where the Z and W particles were found by the group led by Carlo Rubbia. Rubbia was subsequently awarded the Nobel prize for the discovery.) The major detectors at CERN have also been upgraded. By comparison, our Tevatron Collider is higher by a factor of three in energy, but has lower luminosity. This means it will be competitive for most processes, but dominant only in a few. Also at CERN, LEP, the Large Electron Positron ring, is scheduled to turn on in 1989, with four state of the art detectors. The Stanford Linear Collider has enormous interest as a totally new experimental tool, the single pass collider, and will start generating experimental data earlier than LEP. In comparison with LEP, however, it will be dominant only in special classes of experiments that are made possible by the detailed characteristics of the collider itself. Finally, in Germany, the electron-proton collider HERA will turn on in 1991, and in 1993 an upgraded LEP, LEP II, with twice the original LEP energy, will turn on at CERN.

It is a wonderful fact that high energy physics, like almost all science, is an international activity, carried out by an international community of scientists. There are U.S. high energy physicists working on most of the major experiments at the European and Japanese accelerators. My own institution, MIT, for example, has one experimental group preparing for a large LEP experiment, and another group that has participated importantly in the CERN proton-anti proton collider program. Thus we in the U.S. benefit from the efforts of our international colleagues, as they do from ours. In a very real sense, there is already an international high energy physics laboratory with accelerator centers in Batavia, IL; Stanford, CA; Geneva, Switzerland, and so on, with complementary programs, and with scientists from all over the world working at each one.

program, and the model completed. For example, a sixth, as yet undiscovered, quark is predicted by the model. The presently proposed funding will not permit all of the U.S. programs to proceed optimally. I do believe that it will be possible to achieve most of our goals, although at a slower pace than desirable. However, *we must exploit the front line facilities and detectors which we have been preparing for the last five or six years, and which are now ready,* or *almost ready, to run.* This is especially the case because of the very strong international competition discussed below.

The President's Budget Request ~~for~~ the Super Collider includes funds for Research and Development, Capital Equipment and Construction. *The $80M Research and Development and Capital Equipment request is essential to the orderly progress of the project.* It is also very important to obtain construction authorization and end the damaging uncertainty surrounding the project. *If the entire requested budget cannot be authorized, I would at this time give first priority to the Super Collider Research and Development program (including the associated equipment) and to the major elements of the base program, and second priority to the specific level of construction funding in FY89.* It is vital, however, to have sufficient construction funds to permit engineering development by industry.

The Super Collider project badly needs a management structure that can sensibly guide the project and speak for it, for example, in negotiating international participation. The Super Collider will be part of a physics laboratory, and it is important that that management structure be appropriate to the nature of the project. Fermilab and Brookhaven, managed by consortia of universities, with boards composed of scientists and university administrators, are good models. The role of industry in carrying out the construction will surely be a major one, but that is a separate issue and should be arranged by the laboratory management. We need to appoint a contractor and a director, and I don't believe we need to wait for project authorization to do so. The existence of someone who could speak and negotiate for the laboratory would be helpful to the scientific community, to the Department of Energy, and to the Congress as it considers funding issues. It would surely help rationalize a process that up to now has proceeded in fits and starts: we have no project authorization, but we have an elaborate site search; we have no contractor or director, but we have a FY89 budget request of $363M; we are planning a four or five billion dollar project, but in FY88 we have a Research and Development budget of $25M, from which $8M may have to be subtracted for the site search process, a net of less than the FY87 budget. It is terribly important to bring order into this process.

2. The impact of the Superconducting Super Collider program on the overall activities in high energy physics over the next few years:

There is wide agreement in the high energy community that the Super Collider is the necessary next step. *However, the funding for the first few years of construction should* *not* *be taken out of the present program.* As I said earlier, during the last five or six years we have been preparing major front-line facilities and detectors: the Tevatron Collider at Fermilab, the Stanford Linear Collider at SLAC, their associated detectors, and the detectors for experiments in Europe and Japan. These programs should be carried through, so that for the first few years of Super Collider construction the base program funding should not be cut. *By the time the Super Collider has been built, much of the base program will have been accomplished, and many of our present facilities will no longer be at the forefront. Thus, a substantial fraction of the people working in the base program will have transferred their efforts to the Super Collider, and a corresponding shift in budgets will have been made.* Quite aside from budgetary considerations, because of the limited number of people available it will not be possible to create a new Super Collider laboratory and also keep the existing laboratories at their present strength. In addition, of course, as facilities come to the end of their useful life they will be shut down. Our record in turning off programs and accelerators that are no longer at the cutting edge is good: we have turned off the ZGS, the Cosmotron, the PPA, the CEA, and converted the Bevatron to a heavy ion accelerator. The High Energy Physics Advisory Panel will be working with the department on plans for accomplishing the transition.

3. The progress of high energy physics in the United States relative to our international colleagues:

I have to say that we are no longer the leader. Europe has recovered from the war, and regained its scientific strength. *Europe's high energy budget is now about one and a half times ours; its high energy budget ratio to GNP is twice ours, and even during the Super Collider construction years our ratio would only rise to the present European one.* That is certainly part of the reason for their success. In addition, they have planned well and exploited their resources well.

It is clear from all this that we will have to work hard to maintain a competitive position in the pre SSC era. The most urgent need is to continue upgrading the Tevatron Collider and its detector facility to produce a higher luminosity and more complete and accurate data acquisition. We must also, over the next few years, continue upgrading the Stanford Linear Collider to bring its luminosity into a range that will be competitive with LEP.

4. Options for the high energy physics program should the schedule for the SSC project be stretched and annual funding be substantially below the Department's request for the next three to five years:

It is hard for me to give a precise answer to this question. In general terms, it is clear that a construction project like the SSC cannot be stretched out too much without losing the continuity of effort, the enthusiasm and the commitment of the people who have to build it. The time scale is set by the length of human life, and the pace of technological change. Eight years is already a long time. *I would guess that ten years is a kind of limit and that if the project stretches much beyond that, it might better be cancelled.* The cancellation of the SSC project would of course be a very serious blow to high energy physics, not just in the U.S., but in the world, and not just to high energy physics, but to basic science in general. The SSC has been the agreed upon goal of the U.S. high energy community since 1983. With the present program in high energy physics completed in six to eight years, there would be no next step for the field.

Whatever the construction schedule, the present uncertainty creates serious difficulties for the high energy physics effort. Most of my colleagues believe there will be an SSC, are eager to work with it, and are planning their experimental programs and their lives so that they will be able to do so. It is hard to do that effectively in a climate of uncertainty.

As you consider authorizing the SSC project this year, I hope you will keep in mind the enthusiasm and commitment of the high energy community. These individuals are eager to extend mankind's knowledge to frontiers that were unimaginable just a few decades ago. The extension of knowledge of this kind about the fundamental aspects of nature has been and will continue to be one of the greatest accomplishments of civilization.

Thank you. I would be happy to answer questions.

PANEL 1 DISCUSSION

Mr. **Chapman**. Thank you, Dr. Low.

If I may begin by just asking the question, and this may be a little unfair asking you perhaps to get into the mind of one of your colleagues in the business, but based on what Dr. Decker has told us and what you have told us, why would Erich Bloch make what is seemingly such an irresponsible statement as to suggest perhaps that NSF is going to withdraw its support of these programs that are so vital, particularly from the point that you made so eloquently here, the university aspect and the role that plays and how that fits in the puzzle? Why would that even be suggested?

Dr. **Low**. I am not sure I am particularly competent to answer that. I think the NSF, I think Mr. Bloch was very disappointed in the budget that he received, was not able to do what he wanted, and is desperately looking for a way to do some of the things he wants to do. He correctly observed that the NSF only supports one-tenth of the effort. That is true but I think it is not the relevant fraction.

I disagree with him. I understand his motivation. If I were the director, I would be tempted to do that. I think I wouldn't.

Mr. **Chapman**. Then I know that it is frustrating in these budgetary times for all of us. There are things we have that we perceive to be very important priorities for this country, and we run right smack dab into these budgetary constraints in trying to deal with some very real needs.

Dr. **Low**. I do think the long-term effect of this short-term measure would be very damaging to the NSF itself as well as to the field. It is unbelievable to me that our National Science Foundation not be seriously involved in what is one of the basic and profound physics programs in the country.

Mr. **Chapman**. Let me ask Dr. Henley a question. I am a little confused, Dr. Henley. I was reading your testimony and then what you have told us this morning. I want to be sure I understand. Your testimony seems to, or, in fact, does, say that the CEBAF and RHIC are complementary; yet it seems to indicate that we should not begin construction of RHIC until the completion of CEBAF. Surely I misunderstood that if they are complementary facilities, particularly in light of some other testimony before this Committee. Surely I misunderstood that we should not continue moving forward on RHIC as soon as possible since they are complementary facilities.

Dr. **Henley**. I thank you, Mr. Chairman, because this gives me an opportunity to clarify my testimony. I certainly did not intend that. The Nuclear Science Advisory Committee would like to see the construction, the beginning of construction of RHIC as early as at all possible. What I meant to say is perhaps that we would not like to see that at the expense of delaying further the completion of CEBAF.

Mr. **Chapman**. But we are in no way to read into your comments that they should not be developed contemporaneously.

Dr. **Henley**. By no means did I intend to say that, and I thank you for allowing me to clarify.

Mr. **Chapman**. Dr. Henley, the Committee appreciates that clarification as well. The Committee's feeling is that both projects are vitally important and should be developed.

Dr. **Henley**. I totally share that sentiment.

Mr. **Chapman**. Thank you very much.

Dr. Henley, what would be the impact in heavy ion physics research if the Relativistic Heavy Ion Collider Program were delayed significantly beyond its present expected date of completion?

Dr. **Henley**. Not only would research fail to be carried out, but I have grave concern that similar research will be attempted elsewhere. Although as I already indicated, CERN cannot reach the conditions that the Relativistic Heavy Ion Collider will reach, they are attempting to approach those conditions, and it would be a shame if they found the phase transition, for instance, with the injector that they are constructing.

So I think it would cause us to lag behind others in our efforts and it would not allow the research which should be carried out to be carried out in a timely fashion. I think it would be a shame.

Mr. **Chapman**. You had said in your testimony that there was a shortage of nuclear theorists relative to their experimental colleagues. Can you go a step farther and express, in your opinion, for the Committee, if this is a problem with university education? Is it attractiveness of the field? Or, is it strictly a matter of funding?

Dr. **Henley**. I will express an opinion. But it is my own, and I am a nuclear theorist, so you have to take that into account. I do not believe that it is a matter of supply or with the educational system. We find many students who are interested in nuclear theory. I believe it is a problem of funding.

Mr. **Chapman**. Professor Low, the Department has advised this Committee that international agreements for cooperative funding in support of the Superconducting Super Collider project cannot be consummated or even aggressively pursued until the Congress authorizes the project and approves construction funding. Do you concur in that view that we cannot be moving forward in those efforts at this time?

Dr. **Low**. I think it would be extremely helpful to have construction funding and authorization. I think the most important thing would be to have a director who could speak for the project.

But, of course, until the project is actually authorized and some funding is into it, people will not commit themselves definitely. So, I think that's correct. I don't think we could start negotiation until we had a director.

Mr. **Chapman**. Once the project is authorized and Congress passes a law that says we are going to do it and we embark on the appropriations to build it, why, then, should the international community deal with us, when they say Congress is going to pay for this, the American taxpayers are going to finance it?

Why should they, then, participate? Does it not seem to follow that while we're struggling with funding would be the time the international community should worry enough about it to help us?

Dr. **Low**. Well, in the first place, they will absolutely want to participate in experiments there. There's no question that they will do that. And that immediately means sharing in the expenses of detectors.

In the second place, there is a precedent. The German accelerator HERA, a fair measure of its construction has been funded by other countries. The Italians, for example, have supplied half the magnets. They wanted to supply more, in fact, but the German government decided that they didn't want that much external funding.

So, it has happened in the past, and I think it will in the future. Because people will want to have an intense and close association with the project.

Mr. CHAPMAN. When I was in Germany, the attitude of the director there seemed to be that: we've done our accelerator on an international cooperative basis, international funding sharing. You guys didn't participate.

In fact, I'm not real sure we were even invited. But, at any rate, we didn't participate.

And their position was: we're doing our bit for higher energy physics. Why then should we, and that entire collective group of countries, participate when America is not involved in this? Yet, we are gracious enough to share our facilities with you. You have, they told us, 400 physicists here doing research.

This was at CERN. And, I think, at DESY probably would be even a larger number than that, or total number.

But it just seems to me that we should be aggressively pursuing these kinds of negotiations, particularly if we're talking about $300 million this year. Next year the number will grow to the point, I think, they project some $900 million a year necessary during the construction of the project.

And I am quite mystified, in fact, that we're not aggressively pursuing that, if we're serious about international cooperation from the funding side. And it would seem that it would be most helpful to be very active in that at this time.

And let me add, I wholeheartedly concur that we need a director, we need management, we need coordinated efforts. And certainly that would assist in these efforts. And I think your point there is extremely well taken.

Dr. LOW. I agree with you completely on that, sir. I think one of the things the director can do is negotiate in-kind assistance, which is the one that we're most likely to get. And, in fact, the director of DESY, Dr. Soergel, when I talked to him, was quite optimistic about European participation in that mode, as opposed to simply supplying funds.

Mr. CHAPMAN. The observations that you've made, Dr. Low, about this, from the standpoint of structure and management, have you discussed that with the Department?

Dr. LOW. Yes, sir.

Mr. CHAPMAN. And what's their view of their response to the points you made?

Mr. LOW. Yes. I believe the response I've gotten is the same one that Dr. Decker gave you earlier.

Mr. CHAPMAN. We'll organize it when Congress funds it?

Dr. LOW. I think they would like to be more sure of congressional approval, and they're concerned that this is moving too far ahead for the Congress. I don't understand that concern, in view of what has happened with the site search. Which is certainly as definite a set of steps as one can take. So, I'm highly mystified myself.

Mr. CHAPMAN. Well, if we had had a director, could it perhaps be that this $8-million glitch might not have happened over at DOE? I don't know that we're talking about, apparently, this——

Dr. LOW. I do hope something can be done about that. It's a disaster.

Mr. CHAPMAN. Well, I think that certainly this Committee is going to attempt to do something about it. But, at the same time, it requires us to ask some questions on how that happened. And perhaps you may have suggested, with your observation, part of that answer.

Mr. Morrison?

Mr. MORRISON. Thank you, Mr. Chairman. Dr. Henley, first—well, to both of you—appreciation. We know that many of you give of your time to serve on these advisory groups, and we count very much on the results of your deliberations. Dr. Henley, we're particularly pleased with your work at the University of Washington.

I noticed in your testimony you emphasize that inflation factors reflected in the cost to academic institutions, under these budgets, just failed to measure the real world. That, in fact, costs are considerably higher. And, for that reason, we actually are budgeting, even if we intend to keep up, at a net loss.

Now, would you care to expand on that and the reasons why costs seem to be higher than would be reflected in a market basket approach like the Consumer Price Index?

Dr. HENLEY. As I mentioned to you, Mr. Morrison, there was a subcommittee that studied 20 laboratories. Some at universities and some at National Laboratories. They studied inflation factors which, in fact, did not include indirect costs, and did not include what I call sophistication increases in equipment, which also add to the cost.

They found that the inflation factor was almost twice the CPI index. And the reasons were, primarily, that faculty, post-doctoral, student salaries have increased faster than the inflation factor. And that the costs of tuition have increased faster, as well. By almost twice. The average is almost twice. In some cases, the factor is bigger than two times. Sometimes it's as large as three.

It is difficult for me to know the exact reason, but I would guess that, for during the period when inflation ran much higher than it runs at present, faculty salaries did not keep up with inflation. At the present time, there is somewhat of a shortage of outstanding faculty, and there is considerable competition, for both outstanding faculty and postdoctoral research associates. And I believe that competition may be driving the costs up.

Mr. MORRISON. Thank you. I wanted that, again, to be part of the record, because to me that seems very apparent as we look at, even just general, university expenses.

Dr. Henley, your committee also is part of the National Science Foundation. I am wondering if you would have any comments on their budget, as you would see it. While we're not addressing that directly this morning, I'm interested in your observations there.

Dr. HENLEY. The budget during the present FY 1988, I believe, is disastrous. Like my colleague, Dr. Low, I believe that the intent of NSF to withdraw from high energy physics would also be disastrous for the field. And I concur with what he said.

I support the increase recommended by the President for the National Science Foundation for FY 1989, which is a considerably higher increase. That will go a long way toward resolving some of the problems created by the present budget during FY 1988.

I don't know if that answers your question.

Mr. MORRISON. No, that's helpful. We can't go into it in depth. But I was afraid you were going to say that, that that's woefully inadequate.

One question, Dr. Low, for you. I put to Dr. Decker your statement that the Super Collider needed a management structure and appointment of a director. And I think I got sort of a chicken and eggs kind of answer. That, if we'll provide the funding, that, in fact, those things will come along.

And, yet, my concern is that, until we have a voice for the Collider, that, in fact, we may not build the political support that will provide the funding. Would you care to expand on this need, as you see it?

Dr. LOW. No. I agree completely with that. That's correct. I don't myself believe that we have to have Congressional approval, authorization, or construction funding to have a director. I don't think we always have in the past, either, in these projects.

Certainly, in negotiation with the international community, the only person who can do that sensibly is the director, in beginning to think about how the Collider is actually going to be built. That is, somebody has to review the conceptual design proposal and go to work on it. There has to be a director to do that.

Mr. MORRISON. So, you would encourage the Agency to charge on ahead and make this——

Dr. LOW. Absolutely.

Mr. MORRISON [continuing]. Structural step, even without authorization, just for the sake of getting on with the game.

Dr. LOW. Yes, sir.

Mr. MORRISON. Thank you very much. Thank you, Mr. Chairman.

Mr. CHAPMAN. Mr. Fawell?

Mr. FAWELL. I keep having to correct people. That's Fay-well. I'm getting a lot of letters yet for Jerry Falwell. [Laughter.]

And I want to make it perfectly clear.

Mr. CHAPMAN. I apologize, Mr. Fawell. I got some of that same correspondence.

Mr. FAWELL. I would like to follow up in regard to the question just put to you and Dr. Low. Have you talked directly with Dr. Decker and emphasized your feelings that a director would be very helpful?

Because I hear this over and over again, the chicken and the egg conversations, that we can't go ahead and vigorously pursue this. Or, having vigorously pursued, obtain foreign contribution commitments until such time as Congress makes a decision.

And Congress says, "Well, we don't really know what the total amount is, and the budget is terrible, and all that." And so, perhaps we're not making any progress. Have you communicated forcefully on this point?

Dr. LOW. Yes, sir. But it is an advisory position, and the management has its reasons.

Mr. **Fawell**. One of the points which you mentioned, which I jotted down, is bringing out that the first mode in the plan that is now in being in utilizing Fermi and other entities will, by the time the SSC is ready, be pretty much, not fully accomplished, but apparently you indicated, as I construed your remarks, that there will be a lessening of demand of operating costs. Hence, the increase coming on line, operating costs of the SSC would be helped. Is that correct?

Dr. Low. I believe that will be the case. That some of the present budget for the base program will be transferable to the SSC without damaging the whole program.

Mr. **Fawell**. Well, I'm glad to hear that. At least, that had escaped me before, but it's a very logical conclusion, I believe.

Dr. Low. I should say that the present base program, the budget, I believe it is an adequate budget. But it's a tight one. And, as I said in my written testimony, it will require that choices be made. I think we can make them. But it is tight.

Mr. **Fawell**. Dr. Henley, what you have indicated is what I would refer to as a consistent lament we are hearing in regard to all the various sciences. That is, that everyone wants a timely construction without the stretch-out of funds. And at the same time we want the on-going programs not to be, in any way, damaged.

The more I look at what we have, the more difficult that seems to be. We're getting stretch-out of construction funds, not only in the science area, but DOD. And I think it is probably the most costly way to do it. But that seems to be something that the Administration is concluding is one way of trying to handle the tremendous deficit.

I'd like to just throw this question out. Perhaps the world in general can't afford these tremendous facilities without having more cooperative funding, and that more cooperation in general is needed. Each time I've heard the question put, what will happen if this isn't funded and we don't construct by 1995 and instead it won't be on-line until 1997 or 1998, and always it's questioned that some other country is going to be moving ahead of us. And that's perfectly understandable.

Has the time come, though, for strenuous efforts to be made in the long-range planning to say this is something that Japan ought to do, and the United States will do this and Europe will do this? Or is that just pie-in-the-sky?

Dr. **Henley**. Let me comment on the question of international cooperation. Indeed, both the Department of Energy and the Nuclear Science Advisory Committee continue to look into cooperative ventures. In particular, there are such possibilities with Canada on major pieces of equipment, as well as on funding of major facilities.

The question you are raising with regard to, should one reexamine the long-range plan with regard to the on-going base program relative to new construction of facilities, clearly that is on-going, even without reexamining the long-range plan. There is an ongoing look at exactly that question. Namely, whether, indeed, one can continue all of the activities in the base program in light of the new construction.

It is a question which both the Depart [illegible] of Energy and, when requested, the Nuclear Science Advisory [illegible] mmittee do examine, even without reexamining the whole lon [illegible] e plan.

Mr. FAWELL. I guess the SSC is a good [illegible] ple. There's no question, I gather, the SSC will be built. It's [illegible] stion of where it will be built.

And I gather that Europe is looking [illegible] ind of holding their breath, and the Soviet Union, Japan, a [illegible] ers. And we feel it's very, very important and ought to be bu [illegible] e.

But I feel that there's not a whole lo [illegible] mmunication, really, [illegible]

Dr. LOW. Mr. Fawell, I think there is [illegible] nunication. It's clear that the next major step in high energy [illegible] ics is something like the SSC.

I think if there had been a negotiation [illegible] would naturally have come here anyway. Because, in fact, as [illegible] Rubbia, the Director General designate of CERN, told us, Eur [illegible] s its plate full.

They have an upgraded P-bar-P collid [illegible] ning on now and upgraded detectors. They have the LEP [illegible] on-positron machine coming on in 1989. They have LEP II co [illegible] on in 1991, a doubled energy LEP. They have HERA, the elec [illegible] roton collider coming on in Germany in 1990. I mean, they h [illegible] is coming generation of improvements there.

So, in fact, I think negotiation would [illegible] led to something in the United States. I do agree. I think [illegible] ational collaboration and planning is a good thing to try. I [illegible] y difficult, with our funding system and our control system [illegible] heirs, to get together and say, we'll do this and you do that.

Particularly in high energy physics, t [illegible] e after the next one. After the proton collider that we're tal [illegible] bout, there's clearly going to be an electron-positron collid [illegible] e one problem with that, one TeV on one TeV, for examp [illegible] that nobody knows whether it can be done, and maybe five [illegible] years of research is required to find out.

And, so, it's hard to get anybody to co [illegible] themselves to taking that one after this one. There are all [illegible] f political, technical problems in the way of doing it.

I agree with you in principle. It would [illegible] very fine thing if we could manage it.

Mr. FAWELL. Perhaps the world just [illegible] quite ready for that type of international cooperation. It's al [illegible] truck me as interesting that the business world, perhaps, in [illegible] l of everyone else in terms of global economy and globally h [illegible] o work together and so forth and so on. And the rest of us, p [illegible] lly and scientifically, et cetera, are perhaps laggards, which w [illegible] mately catch up.

Dr. LOW. The existence of CERN, of co [illegible] was a remarkable example of that happening. And the exist [illegible] f CERN is what has made possible European progress in high [illegible] y physics.

I personally—and now I'm not speak [illegible] anybody, just me—would welcome some kind of formal a [illegible] re internationally. I think many of my colleagues would dis [illegible] strongly with that. I don't know if Richter and Lederman a [illegible], but you might ask them.

Mr. **Fawell**. I have no further questions. Thank you to both of you.

Mr. **Chapman**. Mr. Hochbrueckner?

Mr. **Hochbrueckner**. Thank you, Mr. Chairman. Dr. Henley, in looking over your testimony, on page 1, I was pleased to see your strong support for the RHIC program, the Relativistic Heavy Iron Collider. I would assume, then, from your perspective, you would be supportive of us beginning the construction phase on that program.

Dr. **Henley**. Extremely supportive, yes.

Mr. **Hochbrueckner**. Okay. Let me ask a more general question of you. You know, I've had colleagues say to me when I indicate that I'm supportive of the SSC program, they've said, "Well, what's in it for us, what's the payoff? And, from my perspective, I can't point to any one thing and say, the SSC, by making this investment, will produce the following end result at some point in the future, since no one can predict the future.

The analogy I tend to use, though, is to point out to them that, when the Government was asked to fund synchrotron technology, we never envisioned that synchrotrons would be a source of x-rays that could put us back in the game in terms of x-ray lithography in producing the next generation of computer chips.

Is there some other defense that I could use, other than the one I do use, which is to say that it pays to make basic investments because at some point the path will be clear and there will be an answer, but we don't have it for you yet?

Or, is there some future expected result that the scientific community is looking forward to that they expect SSC to produce that I could point to, other than using this analogy with the synchrotron?

Dr. **Henley**. I think it's very difficult to say what the future results will hold. So, I don't know a specific answer. But, if you look at the history, I think you will find that, in all cases where fundamental understanding has improved, it has led to considerable applications of all varieties. Superconductivity is certainly a prime example, where basic understanding led to an advance.

Mr. **Hochbrueckner**. So, from your perspective, I could stick with my analogy of x-ray lithography and synchrotrons. Dr. Low, would you have a comment on that?

Dr. **Low**. Yes. Can I comment on that? I think the important reason for going ahead with the SSC is that it is a remarkable human adventure to explore what is there, find out what the world is made of and how it works. And that's the major reason.

The progress that we've made in this in the last 20 years is phenomenal. I never expected to see it. And there is reason to think that we will get closer and closer to understanding the way things work, with this SSC level.

And then you add to that, I think, what Dr. Henley said. The history of pure science is that it leads to technological fallout. And every once in a while, rarely, but every once in a while, and totally unpredictably, leads to serendipitous discovery which changes our lives.

In my written testimony I cited a famous remark of Lord Rutherford in 1933. He said, anyone who looks to the transformations of atoms—he meant nuclei—as a source of energy is talking moonshine. That was 1933. In 1942, the first nuclear reactor was put together in Chicago, nine years later.

Mr. **Hochbrueckner**. So, it sounds like I should stick with my x-ray lithography/synchrotron analogy.

Dr. Low. Absolutely.

Mr. **Hochbrueckner**. Okay. Thank you. Thank you, Mr. Chairman.

Mr. **Chapman**. Mr. Hochbrueckner, let me tell you, out in east Texas we might not even understand that analogy. Those are awful big words for us out in the country, so get down to something a little simpler.

Mr. **Hochbrueckner**. Mr. Chairman, I can whip out my computer, my chip here, and talk about that. Show and tell is always useful. But I'll save that for another day. Thank you.

Mr. **Chapman**. Gentlemen, thank you so much for your testimony today. We appreciate your being with us.

[Questions and answers for the record follow:]

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April 26, 1988

Marilyn Lloyd, Chairman
Subcommittee on Energy Research
and Development
U.S. House of Representatives
B-374 Rayburn House Office Bldg.
Washington, D.C. 20515

Dear Honorable Chairman:

This letter answers your request for a response to questions posed by the Subcommittee on Energy Research and Development.

1. "In your deliberations for FY 1989, have you taken into account the realities of the budget in establishing what should or shouldn't be done?"

At the time of the Nuclear Science Advisory Committee's (NSAC's) last meeting, the President's budget for FY 1989 was not known. Thus, we could not take into account "the realities of the budget" in our discussion. Furthermore, because NSAC advises the Department of Energy and the National Science Foundation, discussion tends to focus on physics and its quality and importance rather than on the budget.

2. "Do you have recommendations of how Congress can deal with these matters?" (choices between construction and on-going research)?

I do not have a good answer to this difficult question. Both new construction and on-going research need to be adequately supported. The NSAC and I believe that the focus should be on making certain that the best science is supported adequately and is made possible by the construction of appropriate facilities.

3. "What would you recommend as an appropriate annual rate of growth for nuclear physics operating expenses?"

Based on the report of NSAC's Subcommittee on Inflation, accepted by the full committee, I believe that the necessary annual rate of growth of the operating budget at the present time is 7-8%, about twice the (CPI) inflation index.

4. "What do you see to be the funding shortfall in FY 1989?"

The shortfall is primarily in three categories:

a) Approximately $20 million in operating expenses, which comes from past shortfalls as well as projected ones. In view of budget realities, let me point out that a 7.5% increase over the FY1988 budget would require an additional $3.5 million over the President's proposed budget.

b) A shortfall of $20 million for the construction of CEBAF. As pointed out by Dr. Herman Grunder, this shortfall will extend the construction period by six months with an accompanying increase in cost as well as a delay in the exploitation of the physics at that facility.

c) Funds to begin construction of the RHIC project. All the planning has been carried out, so that construction could begin as soon as funds are allocated.

Let me turn next to the additional questions posed by the Republican members of the Subcommittee.

1. Information about a Theory Institute:

The Theory Institute could be based at a national laboratory or at a University. It is my own view that it should involve students and, therefore, at a minimum should be close to a university if national laboratory based.

The preliminary report of the NSAC Subcommittee on Nuclear Theory had a good statement on the need for such a Theory Institute. I therefore quote from this preliminary Subcommittee report:

"The broad intellectual opportunities of nuclear theory and need to focus efforts to meet these challenges make the creation of one or more centers for nuclear theory timely and potentially effective. There are many advantages of such an arrangement. By concentrating personnel and activities, centers would provide the critical masses of permanent and long-term people and the critical flow of visitors that can be so conducive to breakthroughs in the field. They could promote interactions between the various subfields of nuclear theory and between nuclear science and related fields. They would also attract and stimulate graduate students and young scientists.

"Any Center for theoretical nuclear physics must be created to serve the whole community and to act as a center for the broadest range of problems in the field. Although contemporary problems of nuclear theory must be the focus of a center, one of the larger benefits of a center for theory is its ability to promote the interaction of nuclear physics with other fields, such as high energy, condensed matter, atomic and molecular physics, and astrophysics."

Although NSAC has not yet approved the report, I believe that the full Committee would agree with the above rationale, as I do. As stated in my testimony, NSAC members and I do not believe that such an Institute should be created at the expense of an adequately funded base program, and, if funded, should be chosen in an open competition.

2. The NSF Budget:

I have had an opportunity to explore the Nuclear Physics budget of the NSF. I was pleased to see major increases in both the intermediate energy and the remainder of the nuclear phsyics programs. These increases will be required if newly completed facility upgrades at Indiana University and Michigan State University are to be used effectively by the U.S. nuclear physics community. Without such increments, the country will not reap the rewards of the investment made to upgrade the facilities. In addition, NSF proposes to fund detector development by university groups preparing to carry out experiments at major facilities such as CEBAF. Again, these incremental funds are needed if the best science is to be carried out at the new major facilities.

I hope that I have answered all the questions to your and the Committee's satisfaction. I will be happy to respond to any remaining questions.

Sincerely yours,

Ernest M Henley

Ernest M. Henley
Chairman, NSAC

EH/jl

Responses to Questions for the Record

from Francis E. Low

Question:	What, in your view, are the R & D priorities that must be addressed this fiscal year as well as FY 1989 as they relate to the SSC program?
Response:	The clear priority in FY 1988 is to continue the development of the superconducting 6.6 tesla dipole magnets. In FY 1989 attention must also be paid to other elements of the integrated system: quadrupole magnets, cryogenic components and refrigerator system, injector, etc. The precise order and scale with which these elements should be pursued must be determined by the Central Design Group.
Question:	Do you perceive that there is a real possibility that funds will be drawn away from other activities within high energy physics in order to support activities in the SSC should the Congress not meet the $80 million R & D required funding in FY 1989?
Response:	I believe this question would be answered by the Congress itself by its R & D appropriation for the SSC. however, should the Congress leave open the possibility of transferring major funding from the base program to the SSC (assuming the base program is funded at the requested level) I would not at this time be in favor of doing so. As I wrote in my prepared statement, and comment on below in response to a later question, the requested funding for

the base program is adequate, but will require hard choices. To decrease it significantly would cause serious, probably long term, damage to the program. We have been preparing for experiments in the base program for many years, and it would be wasteful not to carry them out. Furthermore, effective exploitation of the SSC will require that we maintain a strong program in the early intervening years, so that it would be counterproductive to begin reducing the base program too soon.

Question: We understand that if sufficient funds are available to upgrade the Tevatron, perhaps funding on the order of $100 million, that this facility could serve the high energy physics community for several years to come in producing new physics should the SSC be delayed beyond its present scheduled completion date. Could you discuss the matter?

Response: Even if there is no delay in the SSC schedule, there are important reasons for upgrading existing facilities. Although the question related specifically to the Tevatron, this general comment applies as well to the linear collider at SLAC and the AGS at Brookhaven.

The present Tevatron luminosity will permit us to explore new physics in the energy range between the CERN energy (630 Gev) and the Tevatron energy (1800 Gev). However, full exploitation of the Tevatron would require a luminosity upgrade by a factor of ten to one hundred. Ideally, experiments with the upgraded Tevatron should start in four or five years, but should not be thought of as a substitute for the SSC. On the contrary, the upgraded tevatron would be a facility at which physicists would learn how to work in a high luminosity environment approaching that of the SSC. The total cost, I believe, would be considerably higher than $100 million. The marginal cost, however, would probably be about that, with the difference taken out of existing laboratory funding.

Even if the SSC is approved more or less on schedule, the Tevatron upgrade will still be needed for the reasons given above. If the SSC is seriously delayed, it would be essential for the health of the program to carry out such an upgrade.

Question: You state the United States is no longer the world leader in high energy physics. This is somewhat puzzling to us since we are spending more than half a billion dollars on high energy physics per year for operating budgets.

What is the reason we are falling behind, recognizing that the community is using this argument to advocate the SSC?

Can we presume that the United States, in planning and organizing the high energy physics program, is not on a par with the European programs, for example?

Response: I would like to respond to these questions in inverse order.

First, the United States High Energy Physics Program is excellent. Given the constraints under which it operates, it is organized well, planning appropriately for the future, and will continue to produce exciting new research.

The European program has two major advantages. First, it is funded at a significantly higher level than ours. The CERN 1988 funding was 800 million Swiss Francs; the total member state high energy budget is almost twice that, about 1500 million Swiss Francs; in addition, non member states contribute about 2/5 of the costs of specific experiments at CERN. The dollar equivalent is between $750 million and $1 billion, depending on exchange rate assumptions. Second, the funding is more predictable. At CERN, for example, the Director General is given a rolling four year budget, with the first two years firm. These two advantages have been intelligently exploited by the European leadership to bring about the present situation, with major colliders planned to turn on in 1989, 1991 and 1993.

Responses to Republican Member Questions for the Record

Question: On page four of your prepared testimony, you state that you "believe the funding proposal in the President's Budget for the base program is adequate, but will require that hard choices be made." Please elaborate as to the nature of those choices.

Response: The base program in high energy physics proposed by the Department for FY 1989 includes operating the following research programs:

- non-accelerator experiments
- fixed target experiments at the AGS and Tevatron
- collider experiments with the CDF at the Tevatron
- continuing the construction of a state of the art collider detector, the D-zero, at Fermilab
- experiments at the existing electron-positron colliders PEP and SPEAR at SLAC
- experiments at the new linear collider SLC with the Mark II detector at SLAC
- continuing the construction of the new state of the art detector SLD at SLAC
- continuing the preparation and execution of experiments at CERN, DESY, and KEK in Japan.

In addition, the program includes operating and improving the facilities at BNL, Fermilab and SLAC.

The proposed budget for this program will not allow optimum operation on all these tasks. Some of them will have to be delayed. The High Energy Physics Advisory Panel in 1985 recommended a set of priorities for the program, and we are now working with the Department to implement those priorities. I believe that we will be able to do that, within the proposed budget, in such as way that the unavoidable programmatic delays will cause no irreversible damage.

Question: On page five of your prepared testimony you state that "The Super Collider project badly needs a management structure that can sensibly guide the project and speak for it". What, in your opinion, has prevented the DOE from carrying out a competitive procedure to select a contractor?

Response: I believe the DOE is waiting for a positive signal from the Congress before proceeding to name a contractor.

Question: On page nine of your testimony, you state that you "would guess that ten years is a kind of limit, and that if the project stretches much beyond that it might better be cancelled". What are viable alternatives to the SSC?

Response: I have to say that scientifically and technologically there are no viable alternatives at present. Answering the next set of questions in elementary particle physics requires an energy in the SSC range. The reason to cancel the project if it goes too slowly is not that there is a viable alternative, but that the social and technical dynamics of a dragged out project can make the risk of failure too high. Once the project starts, it is essential that it proceed in a timely fashion.

PANEL 2: DOE HIGH ENERGY PHYSICS LABORATORIES

Mr. **CHAPMAN.** Our next panel is Dr. Kaye Lathrop, associate director of the Technical Division of Stanford Nuclear Linear Accelerator Center. And Dr. Leon Lederman, director of the Fermi National Accelerator Laboratory. Gentlemen, welcome.

Please proceed, Dr. Lederman, and tell us what is happening at Fermi. And if you'll summarize your testimony, I would appreciate it.

STATEMENT OF DR. LEON LEDERMAN, DIRECTOR, FERMI NATIONAL ACCELERATOR LABORATORY, BATAVIA, IL

Dr. **LEDERMAN.** Thank you. Mr. Chairman, in January of last year, in 1987, Fermilab initiated the physics program of the proton-antiproton collider. It's the highest energy accelerator in the world at a total energy of about 1.8 trillion electron volts.

This event put into place the last component of a ten-year effort to create a powerful new facility for the advancement of high energy physics. The so-called Energy Saver Doubler, which was the bureaucratic name given to it at the time, was begun in 1979, and beam was first accelerated in July of 1983, the highest energy ever. The physics program, then, began in October of that year.

The Tevatron, as we now call it, turned out to be a splendid machine, and each successive run has improved the performance and the reliability. Two subsequent line item projects developed the Fermilab Tevatron.

One was called Tevatron I and saw to the construction of a source of antiprotons, probably the most complex assortment of storage rings, targets, transfer lines, and studded with state-of-the-art technology for producing, capturing, storing, and compressing huge quantities of these once-exotic antimatter particles.

This Tevatron I made possible the observation of head-on collisions of particles and antiparticles in what we call the collider mode. The second project upgraded the external beam lines from the preexisting 400 billion volt level to the 1,000 billion volt level required for the Tevatron era, and this was the so-called fixed-target mode.

Concurrently with these construction projects, new experimental detectors were initiated, very largely in the university community throughout the nation and abroad, designed to exploit the two modes of Tevatron operation. In the fixed-target mode, some 15 experiments are carried out simultaneously by a population numbering some 937 physicists, including 259 graduate students. These come from 70 U.S. universities and from 17 foreign countries.

In the collider mode, which we initiated in 1987, one major piece of apparatus, the so-called CDF detector, observes the head-on collisions of protons and antiprotons. It is a collaboration of ten U.S. universities, scientists from three national laboratories, and physicists from Italy and Japan, who have, incidentally, contributed about 20 percent of the cost of building that detector.

Smaller collider experiments also took data in 1987, bringing the total population of our user scientists to over 1,300.

The 1987 initiation of the CDF detector, the antiproton source complex and the Tevatron-as-collider was, in our view of course, spectacularly successful.

We have a yard stick in the performance of the CERN collider in Europe where three years were required to accumulate the data Fermilab collected in its first five months of operations.

Our peak luminosity was up to over one third of that achieved by our CERN colleagues after five years of operation. The data emerging from this run is now nearing the publication level, and brings us to within striking distance of our CERN colleagues' total accumulation of data since 1981.

Of course we have higher energy, three times the energy of CERN, and of course, we have all the advantages of profiting from their experience.

Our collider run ended on May 11, 1987, and by June 1 we had turned to the fixed target program. This ran continuously through the end of the fiscal year, and on through the middle of February of 1988.

In 1987, the machine was operated for about 50 weeks, the most we've ever been on in any calendar year in our history. And, this is 24 hours a day, seven days a week, unless the machine broke in which case we had to fix it.

At the end of the fixed-target run some 35,000 high density magnetic tapes full of data were spilling out of the Fermilab Computing Center. This, to us unprecedented utilization, was a result of a conscious decision to make utilization, to make operation of a facility, our highest priority, higher than investing in future experiments, higher than investing in machine improvements, and even higher than all but the most essential maintenance. Obviously, we were skating on thin ice.

We are currently paused to reinstall the colliding detector, improve shielding and make a careful inspection of the supermagnets which have been in service since 1983.

We expect to begin the second collider run in May and to continue this run at least through the end of this calendar year.

Our objective is to accumulate 30 times the data of the first run. We call this the "discovery run." This is because the potential for discovery in such a machine is directly tied to the quantity of data accumulated.

On the longer range, we call for switching back to the fixed target run early in 1989, and doing what we must do to maintain this productive alternation between two complementary modes of operation.

On the one hand the programmatic, precision, detailed study of the properties of the quarks and leptons and the forces of nature which is characteristic of the fixed target program; and on the other hand, the bold salient into the unknown, which one of my students once characterized as a place where no human eyeball has set foot. A master of the mixed metaphor.

The collider mode is newborn, and like all newborns requires constant attention demanding new necessary nourishments, too young to judge, but with this awesome circular glow around its head, we think a harbinger of incredible promise. It has sometimes been called the "jewel of high energy physics."

In contrast, the fixed-target progr [illegible] pproaches maturity, maybe adolescence is a better word, in [illegible] 987 run. Results from the long and successful 1985 run have b [illegible] o dominate the particle physics conferences by the summer [illegible] 5. And, I have submitted for the various tables to try to give [illegible] glimpse of this kind of activity.

What I'd like to stress, and did in th [illegible] es which I'm submitting for the record, is that there was a [illegible] tative advance of the Tevatron and its experiments over all p [illegible] s facilities, in experiment after experiment where a total [illegible] nulation around the world of a handful of events of tens or [illegible] es or a hundred have been multiplied in the Tevatron to ten [illegible] housands to hundreds of thousands, and even millions of event [illegible]

Some hundred Ph.D. theses will be [illegible] n on the date of the 1987 run, and definitive results will be [illegible] ing out over the next several years.

Looking ahead, we see a vigorous pr [illegible] and a worldwide interest in using the Tevatron. The FY [illegible] President's budget request provides funds to continue the op [illegible] n of both the collider and the fixed-target modes.

If this survives Congressional action, [illegible] l continue to give utilization the highest priority. However, [illegible] nportant to list other activities which will be required to ens [illegible] e continued exploitation of the Tevatron investment. Let me [illegible] nese in order or priority.

One is the completion of another coll [illegible] etector facility which we call the "D-ZERO Colliding Detector [illegible] F was designed when very little was known about proton/a [illegible] ton collision results. The results at CERN did not come out u [illegible] 982 and 1983.

Our users, the Program Advisory [illegible] ittee and the High Energy Physics Advisory Panel all co [illegible] d in the need for a second major detector, making use of [illegible] perience of the UA1 and UA2 instruments at CERN, and o [illegible] rovements in detector technology.

The D0 Detector is again another la [illegible] laboration which was begun in 1984 with a goal of completion [illegible] 989. Its design is complementary to CDF and its location in t [illegible] vatron ring was made possible by a tour-de-force of rearrange [illegible] of accelerator components.

Funding limitations here have led to [illegible] tch out of D0 and we do not expect completion before early 1 [illegible] ven this date depends on some modest improvements in the [illegible] 89 President's budget request in the equipment category.

The second level of priority is a cat [illegible] on many things. Deferred maintenance, low stock of spares [illegible] general weakening of the laboratory infrastructure, which [illegible] rought about by our overriding priority of operating and gett [illegible] ta.

Obviously, sooner or later, we have [illegible] ress these important issues. And finally, there is the long ra [illegible] ogram which we call the "Collider Upgrade." The Laborator [illegible] nitted for fiscal 1990 some line item projects aimed at improv [illegible] e collision rate of the collider.

The unique characteristic of hadron c [illegible] s is the translation of collision rate, or luminosity, into effec [illegible] higher energy. The power of the collider depends on this luminosity as well as on its energy. Fermilab scientists have devised an orderly plan for gradually raising luminosity over the next five years to 100 times the design luminosity.

This will double the reach of the Tevatron collider into the domain of the unexplored where new human eyeball, etc., enabling a much more sensitive search for new phenomenon.

Some of this improvement can be funded out of AIP funds, some as a result of R&D investments, however, some improvements will require line item construction funds.

If we are to maintain our leadership, which the Tevatron gives us, over the interval between now and when SSC comes on the air, presumably toward the end of the 1990's, it will require investments of something like $35 million a year in the 1990 to 1993 period. We believe this a modest sum to keep the highest energy machine at the forefront through the 1990's.

In conclusion, we are, of course, very appreciative of the support this Committee has given us in implementing the Tevatron program. It is clearly a success. The superconducting Tevatron has given the U.S. a prototype for the SSC, but it has also given us a powerful tool for doing fundamental research in high energy physics.

All of us are convinced of the necessity of having the 20-TeV collisions before the end of the century. High energy physicists are a community that plans well and far into the future.

The Tevatron is an essential and immediate step that is required to develop the physics, to keep the flow of young scientists into the field, and to maintain the spirit of international collaboration.

I'd like to close by reminding you of a unique feature of Fermilab's international activities. We've had many initiatives with developing countries where scientists and engineers, especially from Latin America, but now increasingly from India, come to Fermilab for visits, carry back the excitement of cutting edge research, the power of our national laboratory system, and above all, the conviction that the road to development lies through science and its associated technology, a lesson of which the industrial countries must occasionally be reminded.

Thank you.

[The prepared statement of Dr. Lederman follows:]

STATEMENT OF LEON M. LEDERMAN
FERMI NATIONAL ACCELERATOR LABORATORY
Committee on Science, Space and Technology
Subcommittee on Energy Research & Development
March 30, 1988

INTRODUCTION

In January 1987 Fermilab initiated the physics program of the proton-antiproton collider, the highest energy accelerator in the world at a total energy of 1.8 trillion-electron-volts (TeV). This event put into place the last component of a ten year effort to create a powerful new facility for the advance of high energy particle physics. Let me remind you of the history since it is instructive.

In 1973, Fermilab began an R&D program on superconducting magnets for accelerator application. Based upon the success of a six year R&D program, construction of the so-called Energy Saver/Doubler began in 1979. Beam was first accelerated in July of 1983 to the highest energy ever and the physics program, using the conventional extracted beam began in October of that year.

The world's first superconducting synchrotron indeed saved power and doubled the beam energy. The TEVATRON, as we now call it, turned out to be a splendid machine and each successive run has seen improved performance and reliability.

Two subsequent line item projects developed the Fermilab TEVATRON. One, called TeV I, saw to the construction of a source of antiprotons - probably the most complex assortment of storage rings, targets, transfer lines studded with state of the art technology for producing, capturing, storing and compressing the once exotic antiparticles. The second project upgraded the external beam lines from the pre-existing 400 GeV level to the 1000 GeV level required for the TEVATRON era.

Concurrently with these construction projects, new experimental detectors were initiated - very largely in the university community throughout the nation and abroad, designed to exploit the two modes of TEVATRON operation. In the fixed target mode, some 15 experiments are carried out simultaneously by a population numbering 937 physicists, including 259 graduate students. These come from some 70 U.S. universities and from 17 foreign countries. Table I lists the participating institutions. In the collider mode, initiated in 1987, one major piece of apparatus, the CDF detector, observes the head-on collisions of protons and antiprotons. It is a collaboration of 10 U.S. universities, scientists from 3 national labs and physicists from Italy and Japan who have incidentally contributed about 20% of the costs. Smaller collider experiments also took data in 1987 bringing the total population of user scientists to 1344.

ACHIEVEMENTS IN FY 87

The 1987 initiation of the CDF detector, the antiproton source complex and the Tevatron-as-collider was, in our view, spectacularly successful. Start-up problems gradually gave way to smooth operation as both accelerators and detectors were brought under control.

We have ~~a~~ yardstick in the performance of the CERN collider in Europe where three years were required to accumulate the data Fermilab collected in the five months of our first run. The antiproton source reached over 10% of its design intensity, an unusual accomplishment for so complex a device. There were other firsts: the highest collection rate of antiprotons ever (incidentally, we've watched antiprotons circulating in their storage ring for over 20 days!). Our peak luminosity was over one-third of that achieved at CERN after five years of operation. The data emerging from this run is now nearing the publication level and brings us to within striking distance of our CERN colleagues total accumulation of data since 1987. Of course we have higher energy and the advantages of profiling from their experience.

The Collider run ended on May 11 and by June 1 we turned to the fixed target program. This ran continuously through the end of the fiscal year and, setting aside the "Perils of Pauline" funding crises, through to Feb. 16, 1988.

The machine was operated for about 50 weeks, the most we've ever been on in any calendar year in our history. At the end of the fixed target run some 35,000 high density magnetic tapes full of data were spilling out of the Fermilab computing center. This unprecedented utilization was the result of a conscious decision to make operation our highest priority, higher than investing in future experiments, higher than investing in machine improvements and even higher than all but the most essential maintenance. Obviously we are skating on thin ice.

SUMMARY OF PROJECTED OPERATIONS

We are currently paused to reinstall the collider detector, improve shielding and inspect the supermagnets which have been in service since 1983. We expect to begin the second collider run in May and to continue this run through at least the end of 1988. Our objective is to accumulate 30 times the data of the first run. We call this the

"Discovery Run." This is because the potential for discovery is directly tied to the quantity of data accumulated.

Our theoretical colleagues have proliferated the number of speculated new particles that we can discover - all of this in their efforts to find a simpler, more unified and more coherent theory of how the universe works. Candidate discoveries have names like "top quark", "gluino", "heavy lepton" and "composite structure of quarks." This forthcoming run can only be compared to the first glimpse of yet unchartered heavens that the Hubble Space Telescope may reveal (if we can ever put that magnificent instrument into orbit).

Our longer range plan calls for switching back to the fixed target program early in 1989 and doing what we must do to maintain this productive alternation between two complementary modes of operation: the programmatic, precision, detailed study of the properties of quarks, leptons and forces of nature characteristic of the fixed target research and the bold salient into the unknown (where no human eyeball has ever set foot) which characterizes the Collider.

ASSESSMENT OF THE PROGRAM

The Collider mode is new-born, requiring constant attention demanding ever new "necessary" nourishments, too young to judge but with this awesome circular glow around its head - a harbinger of incredible promise. It is not a failure of objectivity to agree with the accolade: "The jewel of U.S. high energy physics."

In contrast, the fixed target program approaches maturity in the 1987 run. Results from the 1985 run began to dominate the conferences by the summer of 1986. We list in Table II, the experiments completed in the 1987 run. For its sociological value, we also list the date of approval of the experiments.

What we would like to stress here is the qualitative advance of the TEVATRON experiments over all previous facilities. We do this in Table III as an indicator of the power of the new machine and its complement of experiments. As an example of this, Figure 1 shows the precision in the determination of the lifetimes of some exotic particles, the D^o and D^+ mesons each carrying a charmed quark.

Data analysis is a time consuming and laborious process, carried out chiefly by the graduate students. Some 100 Ph.D. theses will be written on the data of the 1987 run but definitive results will be trickling out over the next several years.

The roughly 9 month cycle is ideal in giving experimenters time to work on data, to improve apparatus and for the Laboratory and the universities to accumulate funds for implementing the required changes.

REQUIREMENTS FOR THE FUTURE

Table IV gives the experiments which will be run in the 1989-1990 period and Table V gives the menu of proposals still to be acted upon by the Laboratory. We see a vigorous program and a world-wide interest in using the TEVATRON. The FY 1989 President's Budget Request provides funds to continue the operation of both Collider and Fixed Target modes. If this allocation survives congressional action, we will continue to give utilization the highest priority. However, it is important to list the activities which will be required to insure a continued exploitation of the TEVATRON investment. We list these in rough order of priority.

I. Completion of the D ZERO Collider Detector

The CDF detector was designed in the 1981-3 period when very little was known about the CERN results. Our users, the Program Advisory Committee and HEPAP all concurred in the need for a second major detector, making use of the experience of the UA1 and UA2 instruments at CERN and on improvements in detector technology. The D0 Detector, another large collaboration, was begun in FY 84 with a goal of completion by FY 89. Its design was to be complementary to CDF and its location in the TEVATRON ring was made possible by a tour-de-force of rearrangements of accelerator components.

Funding limitations have led to a stretch-out of D0 and we now expect completion by early 1991. Even this date depends on some modest improvement over the FY 89 PBR in the equipment category. The Laboratory's ability to assist here has been constrained by the higher priority of machine operation, by the other claimants on scarce equipment funds such as CDF and the need to provide computer power for the analysis of the vast amount of data recently obtained.

II. Catch-up on Deferred Maintenance, Low stock of spares, and General weakening of the Laboratory Infrastructure

The urgent priority of getting data (after the 10 year long construction phase) has been obtained at a cost. Obviously, we must begin to address these issues. Unfortunately, the FY 89 operating and meager GPP levels will still make efforts to catch-up here rather marginal in 1989.

III. Collider UPGRADE

The Laboratory has submitted for FY 90 some line item projects aimed at improving the collision rate of the Collider. A unique characteristic of hadron colliders is the translation of "luminosity" i.e. collision rate, into effective higher energy. When protons collide with antiprotons, it is the constituent quark collisions that provide the new physics, make new particles or illuminate the details of the forces. Since a proton is made of three quarks, the constituent quark-quark collisions are much lower in energy than the protons. However, as the number of observed collisions increases, the rarer collisions of quarks having a larger fraction of the proton's energy increases. Thus the power of the collider depends on luminosity as well as energy. Fermilab scientists have devised an orderly plan for gradually raising the luminosity over the next five years to 100 times the design luminosity. This will double the reach of the TEVATRON collider into the domain of the unexplored, enabling a much more sensitive search for new phenomena. Some of this improvement can be funded out of AIP funds, some as a result of R&D investments. However, some improvements will require relatively modest line item construction funds.

If we are to maintain our leadership via the TEVATRON over the interval between now and when SSC comes on the air, it would take a construction investment of something like $35M a year over the next four or five year period. We believe this to be a modest sum to keep the highest energy machine at the forefront through the mid-1990's.

CONCLUSIONS

We are of course very appreciative of the support this Committee has given us in implementing the TEVATRON program. It is clearly a success. The superconducting TEVATRON has given the U.S. a prototype for the SSC. But it has also given the U.S. a powerful tool for doing fundamental research in HEP.

All of us are convinced of the necessity of having 20 TeV collisions before the end of the century. We are a community that plans well and far into the future. The TEVATRON is an essential intermediate step and is required to develop the physics, to keep the flow of young scientists into the field, to maintain the spirit of international collaboration.

I would like to note in closing that a unique feature of Fermilab's international activities is our initiatives with developing countries where scientists and engineers from many countries in Latin America (and now India) profit from visits to Fermilab and carry back the excitement of cutting edge research, the power of our national laboratory system and above all the conviction that the road to development lies through science and its associated technology, a lesson of which the industrial countries must occasionally be reminded.

TABLE I

Institutions Currently Participating in the Fermilab High-Energy Physics Research Program

Argonne National Laboratory
Arizona, University of
Athens, University of (Greece)
Ball State University
Bologna, University Di (Italy)
Brandeis University
Brookhaven National Laboratory
Brown University
California Inst. of Technology
California, Univ. of, Berkeley
California, Univ. of, Irvine
California, Univ. of, Riverside
California, Univ. of, San Diego
Cen-Saclay (France
Central Design Group
CBPF (Brazil)
Chicago, University of
Colorado University
Columbia University
Cornell University
Delhi University (India)
Duke University
Elmhurst College
Fermilab
Ferrara, Univ. Di (Italy)
Florida A & M University
Florida State University
Florida, University of
Freiburg University (West Germany)
GE R&D Center
Genova, University Di (Italy)
George Mason University
Harvard University
Haverford College
Lawrence Berkeley Laboratory
Lawrence Livermore Laboratory
Lehigh University
Leningrad INP (USSR)
Los Alamos National Laboratory
Louisville, University of, Kentucky
Maryland, University of
Massachusetts, University of
Massachusetts Inst. of Tech.
Max-Planck Institute (Germany)
McGill University (Canada)
Mexico, University of (Mexico)
Michigan State University
Michigan, University of
Milano, University of (Italy)
Minnesota, University of
Nagoya University (Japan)
New York University
New York, State Univ. of, Albany
New York, State Univ. of, Stony Brook
Northeastern University
Northern Illinois University
Northwestern University
Notre Dame, University of
Occupational/Environmental Health,
University of, Japan
Pennsylvania State University
Pennsylvania, University of
Pittsburgh, University of
Princeton University
Purdue University
Rajasthan University (India)
Rice University
Rochester, University of

TABLE I (Cont'd)

Hawaii, University of
Hiroshima University (Japan)
Houston, University of
ICRR, Tokyo University (Japan)
IHEP, Beijing (China)
Illinois, Univ. of, Chicago Circle
Illinois, University of
Indiana University
INFN, Frascati (Italy)
INFN, Milano (Italy)
INFN, University of Pisa (Italy)
IHEP, Serpukhov (USSR)
INP, Cracow (Poland)
Iowa State University
Iowa, University of
KEK (Japan)
Kyoto Sangyo Univ., Kyoto, Japan
Kyoto University (Japan)
Kyoto Univ. of Education, Kyoto, Japan
Lab A Phys. des Particules (France)
Rockefeller University
Rutgers University
Saga University (Japan)
Sandia Laboratories
Sao Paulo, Universidade de, (Brazil)
Shandong University (China)
Stanford Linear Accelerator Center
Texas A&M University
Texas, University of, Austin
Tohoku Gakuin University (Japan)
Tohoku University (Japan)
Torino, Univ. Di (Italy)
Trieste Inst. di Fisica (Italy)
Tsukuba, Univ. of, Ibaraki (Japan)
Vanderbilt University
Washington, University of
Wisconsin, University of, Madison
Wuppertal, University of (Germany)
Yale University

TABLE I'

FERMILAB 1987
DEMOGRAPHICS OF USERS

		Ph.D.	G.S.	TOTAL
Collider:				
	U.S.	310	92	402
	Foreign	66	22	88
		376	114	490
Fixed Target:				
	U.S.	427	207	634
	Foreign	249	52	301
		676	259	935

Note: Some experimenters are participants on both Collider and Fixed Target experiments. Below, we eliminate all duplication.

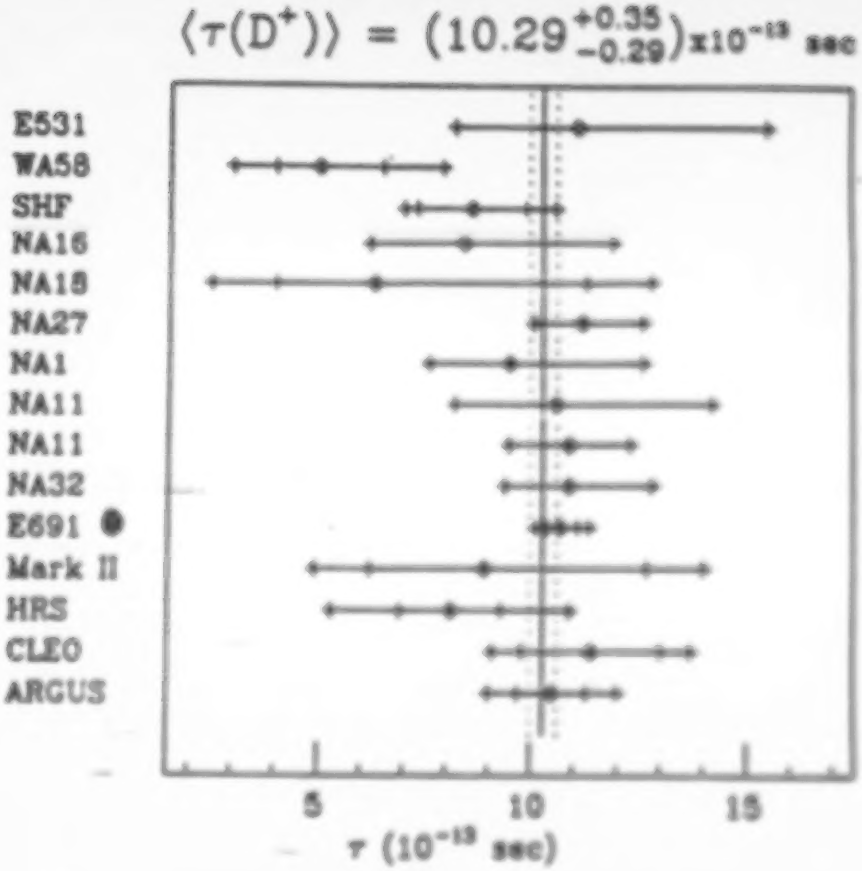
		Ph.D.	G.S.	TOTAL
All Approved Incomplete Exps.				
	U.S.	666	294	960
	Foreign	310	74	384
		976	368	1344

	U.S.	Foreign	TOTAL
Institutions	79	62	141

Foreign Countries 17

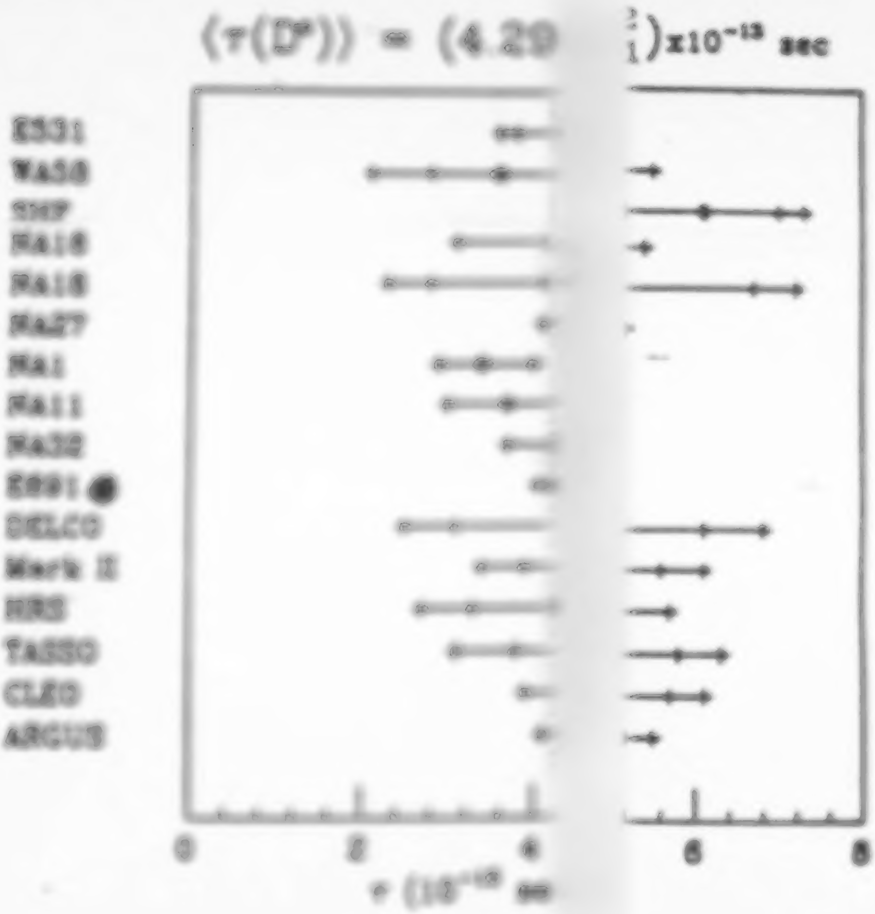
We note that at the last DOE census, there were 3100 U.S. HEP experimentalists (including grad students). Thus FNAL services about 50% of the U.S. users and 10-15% of all foreign [Europe + Japan] users. Approved experiments are a solemn commitment on the part of Fermilab to both foreign and U.S. scientists. The Laboratory was emboldened to make these commitments on the basis of the investment in capital funds (see Chart 20).

FIGURE 1A



E691 is a 1985 TEVATRON experiment. Horizontal bars represent experimental errors. Other experiments are from CERN, DESY, SLAC and Cornell.

FIGURE 1



E691 is a 1985 TEVATRON iment.
Horizontal bars represent orimental errors.
Other experiments are fr RN, DESY, SLAC
and Cornell.

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TABLE II

EXPERIMENTS COMPLETED IN 1987-88 FIXED-TARGET RUN

FIXED-TARGET

ELECTROWEAK

		Approval date	
E-632	(MORRISON/ PETERS)	6/82	WIDE BAND NEUTRINOS IN THE 15 FT BUBBLE CHAMBER (16/84)
E-733	(BROCK)	4/86	NEUTRINO INTERACTIONS WITH QUAD TRIPLET BEAM (4/26)
E-745	(KITAGAKI)	12/83	NEUTRINO PHYSICS WITH QUAD TRIPLET BEAM (10/43)
E-770	(SMITH)	12/85	NEUTRINO PHYSICS WITH QUAD TRIPLET BEAM (4/28)

DECAYS AND CP

T-721	(ROSEN)	3/84	CP VIOLATION (8/44)
E-731	(WINSTEIN)	7/83	MEASUREMENT OF ϵ'/ϵ (5/27)
E-756	(LUK)	6/85	Ω^- MAGNETIC MOMENT (4/16)

HEAVY QUARKS

E-653	(REAY)	7/81	HADRONIC PRODUCTION OF CHARM AND B (19/79)
E-705	(COX)	12/81	CHARMONIUM AND DIRECT PHOTON PRODUCTION (8/47)
E-769	(APPEL)	12/85	PION AND KAON PRODUCTION OF CHARM (8/25)

HARD COLLISIONS AND QCD

E-711	(LEVINTHAL)	7/81	CONSTITUENT SCATTERING (3/23)
E-772	(MOSS)	7/86	NUCLEAR ANTIQUARK STRUCTURE FUNCTIONS (9/26)

OTHERS

T-755	(MAJKA/ SLAUGHTER)	STREAMER CHAMBER TESTS (2/10)
E-776	(BAKER)	NUCLEAR CALIBRATION CROSS SECTIONS (3/7)

NOTE: E = EXPERIMENT; T = TEST. NUMBERS IN PARENTHESES DENOTE TOTAL NUMBER OF INSTITUTIONS AND PHYSICISTS, RESPECTIVELY.

TABLE III

SOME TYPICAL "BEFORE AND AFTER" EXPERIMENTS

I. E-715 BETA DECAY OF THE SIGMA HYPERON
WORLD'S COLLECTION ~ 400 EVENTS
TEVATRON YIELD ~ 80,000 EVENTS

II. E-621 CP SYMMETRY VIOLATING PARAMETER
EIGHT PREVIOUS EXPERIMENTS OBTAINED 12000 EVENTS
E-621 IN 1985 OBTAINED 3 MILLION EVENTS

III. DILEPTON PRODUCTION BY PROTONS
PRIOR DATA: 5000 UPSILON EVENTS WITH 2% RESOLUTION
E-605 20,000 UPSILON EVENTS WITH 0.2% RESOLUTION

IV. K-LONG TO TWO PI ZEROS CP EXPERIMENT
PREDECESSOR 14,000 EVENTS
E-731: 300,000 EVENTS

V. MAGNETISM OF THE OMEGA HYPERON
PREVIOUS TOTAL 16,000 UNPOLARIZED Ω^-
E-756 100,000 Ω^-, 20,000 POLARIZED

VI. NEUTRINO SCATTERING
TEVATRON YIELDED OVER 200,000 EVENTS WITH NEUTRINO
ENERGY OVER
300 GeV. PREVIOUS WORLD'S SAMPLE WAS ZERO.

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CURRENTLY APPROVED FERMILAB EXPERIMENTS

FIXED-TARGET

ELECTROWEAK

E-665	(MONTGOMERY)	MUON SCATTERING WITH HADRON DETECTION (13/79)
E-782	(KITAGAKI)	MUON SCATTERING WITH TOHOKU BUBBLE CHAMBER (7/33)

DECAYS AND CP

E-761	(VOROBYOV)	HYPERON RADIATIVE DECAY (6/16)
E-773	(GOLLIN)	PHASE DIFFERENCE BETWEEN η_{00} and η_{+-} (4/12)
E-774	(CRISLER)	ELECTRON BEAM DUMP PARTICLE SEARCH (4/7)

HEAVY QUARKS

E-687	(BUTLER)	PHOTOPRODUCTION OF CHARM AND B (8/58)
E-690	(KNAPP)	HADRONIC PRODUCTION OF CHARM AND B (5/21)
E-760	(CESTER)	CHARMONIUM STATES (7/59)
E-771	(COX)	BEAUTY PRODUCTION BY PROTONS (9/68)

HARD COLLISIONS AND QCD

E-672	(ZIEMINSKI)	HIGH P_T JETS AND HIGH MASS DIMUONS (7/28)
E-683	(CORCORAN)	PHOTOPRODUCTION OF JETS (9/33)
E-704	(YOKOSAWA)	EXPERIMENTS WITH A POLARIZED BEAM (16/50)
E-706	(SLATTERY)	DIRECT PHOTON PRODUCTION (9/75)

COLLIDER

E-710	(OREAR/ RUBINSTEIN)	TOTAL CROSS SECTION (6/18)
E-713	(PRICE)	HIGHLY IONIZING PARTICLES (2/3)
E-735	(GUTAY)	SEARCH FOR QUARK GLUON PHASE (7/52)
E-740	(GRANNIS)	D0 DETECTOR (20/124)
E-741/ E-775	(SCHWITTERS/ TOLLESTRUP)	COLLIDER DETECTOR AT FERMILAB (20/247)

OTHERS

E-466	(PORILE)	NUCLEAR FRAGMENTS (3/7)
E-754	(SUN)	CHANNELING TESTS (4/8)
E-778	(EDWARDS)	STUDY OF SSC MAGNET APERTURE CRITERION (5/15)
E-790	(SCIULLI)	ZEUS CALORIMETER MODULE TESTS (7/?)

NOTE: E = EXPERIMENT; T = TEST. NUMBERS IN PARENTHESES DENOTE TOTAL NUMBER OF INSTITUTIONS AND PHYSICISTS, RESPECTIVELY.

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TABLE V

PENDING PROPOSALS

P-682	(UNDERWOOD)	POLARIZED BEAM
P-688	(DITZLER)	POLARIZED BEAM
P-699	(STANEK)	POLARIZED BEAM
P-781	(RUSS)	LARGE-X BARYON SPECTROMETER
P-783	(REAY)	TEVATRON BEAUTY FACTORY
P-784	(LOCKYER)	BOTTOM AT THE COLLIDER
P-785	(BONNER/ PINSKY)	LOW ENERGY ANTIMATTER
P-786	(WILSON)	HEAVY QUARKS WITH MUONS
P-787	(GUTAY)	SEARCH FOR QUARK GLUON PHASE
P-788	(BERNSTEIN)	NEUTRINO OSCILLATIONS WITH NEUTRAL BEAM
P-789	(KAPLAN)	PRODUCTION AND DECAY OF B-QUARK MESONS AND BARYONS
P-791	(APPEL)	HADROPRODUCTION OF BEAUTY AND CHARM PARTICLES

Mr. CHAPMAN. Thank you. Dr. Lathrop?

STATEMENT OF DR. KAYE D. LATHROP, ASSOCIATE DIRECTOR, TECHNICAL DIVISION, STANFORD LINEAR ACCELERATOR CENTER, STANFORD, CA, ON BEHALF OF DR. BURTON RICHTER, DIRECTOR

Dr. LATHROP. Mr. Chairman, members of the Committee, Burton Richter, the Director of the Stanford Linear Accelerator Center, was asked to attend a meeting with the President this morning and he regrets that he is unable to be here, too.

I will summarize the remarks that he has made in his written testimony but I would ask that the entire text of his remarks be included in the record, please.

Mr. CHAPMAN. Certainly. All written testimony of all witnesses will be made a part of the record today.

Dr. LATHROP. Thank you. As you know, SLAC is a national user facility. In our good years, we have users from all over the United States and from several foreign countries come to use our facilities. Last year was a bad year for SLAC; because of budget stringencies, it was necessary for us to shut down our storage rings and the pace of the commissioning of our new linear collider was slowed down. We hope to recoup in this year and reach full operating status in next fiscal year.

Let me review the programs that we have undertaken this year, primarily the construction of the linear collider, which was finished about a year ago. Our first commissioning run ended in October. We had one very pleasant surprise during that run. We easily met the design energy required to make the Z naught particle from which so much interesting in physics will flow. We even have reserve capacity to exceed it. We also had some unpleasant surprises. The arc magnet strings that take the beam from the end of the accelerator to the collision point had a difficulty that caused the size of the beams to grow as they went through these nearly mile long strings. At first, we didn't understand that. We now understand this phenomenon which has to do with the fact that these are not magnet strings in a plane. We had saved money by tunneling in the most expeditious fashion through the earth up and down and this caused this phenomenon. We now have it under control.

In October, we made several improvements to the accelerator and the collider, moved the Mark II detector on line and in January we began another commissioning run. One of the things we were most interested to find out is whether stray particles would get into the detector and mask real events that might occur. You will remember, this is a brand new technology and the question of background particles masking events was real.

We have now determined that we can keep the backgrounds to an acceptable level for our first runs and we are very pleased with that.

We have gotten small beam sizes and we have gotten electron and positron intensities that are good enough for a first data run which we expect to begin in May. We are hoping to have new physics results to report for the high energy physics international conference in August.

Although the commissioning has been slower than we expected, we are very excited about the present status of this machine.

The SLAC fiscal 1989 operating budget request is $110 million, an increase of about $12.4 million. After inflation, there is a slight decrease in our General Science and Research funding, so all of the real increase in this budget request is for the expanded operation of our facility, which we expect to be in a position to accomplish.

We will run the SLC for about 32 weeks next fiscal year, compared to only 13 weeks at high repetition rate this year. Our colliding beam storage facilities, PEP and SPEAR, will run in parallel with the SLC. Although the SLC will have priority so the rate of filling these storage rings will not be optimum until we master that switching back and forth between the facilities.

The equipment funds proposed in the President's 1989 budget totaled $22.7 million as compared to $18 million this fiscal year. Next year, as in the two previous years, the bulk of this will go to SLC-related improvements, particularly the SLD detector. This detector is the single largest item in our equipment budget. It will have capabilities far beyond that of the Mark II detector that is now on line and it will give us an experimental facility that is a match for the new generation of detectors being built for the LEP project at CERN. The SLD project is going extremely well and now is paced entirely by availability of financial resources rather than any technical considerations.

Our accelerator improvement budget for fiscal 1989 is $3.35 million. This represents about one percent of the present value of our accelerators, not counting buildings or accelerator housing. In that sense, it is a very small number but it is extremely vital to the continued improvement of the SLC.

There are two main areas here, one, the making of better components to reach the ultimate design luminosity and the other, the improving of the reliability of the machine. Remember, this machine is not only a bold innovative step, it is also a very tricky device. We made use of the existing 22-year-old accelerator to accelerate both electrons and positrons at the same time. It has to work well. I can think of and have thought of many, many projects to use this improvement money on.

For our future programs beyond next fiscal year, the SLC opens a brand new energy range. It will probably remain a frontier facility for the next decade. Our two storage rings while not on the energy frontier have potential for a great deal of highly productive research. To properly exploit all these machines, we should bring their operation up to a practical maximum. That would require in fiscal 1990 about a 15-percent real increase in our operating budget. We will also need in that year an upgrade in our computing facility to handle the increased amount of data. You heard my colleague speak of the warehouses full of tapes they have accumulated. Those tapes need to be processed and reprocessed until the last iota of information is extracted and that takes state-of-the-art computing.

We also have an active accelerator R&D program. We are working on TeV-scale linear colliders and how to solve the problems that are not yet solved. We have begun a fruitful collaboration for power sources for these machines with the Lawrence Livermore

National Laboratory and we have already made progress toward our goal of producing gigawatt-sized klystrons.

We are very cognizant of the need for international collaboration in the construction of such a future machine. While SLAC is the leader in this technology, Europe, Japan and the Soviet Union are becoming more heavily involved. We are trying to internationalize now the research and development for such a machine so each region of the world can tackle problems and contribute.

Toward this end, we are organizing a workshop on advanced linear colliders to be held at SLAC this fall.

This year and next fiscal year should be particularly exciting years in the U.S. high energy physics program. The SLC at SLAC and the Tevatron at Fermilab will begin to produce the physics results that will justify the funds spent on their construction. The realization of the potential of these facilities requires sufficient funding to operate the machines and to support their experimental programs.

While the SSC will be a magnificent research tool when completed, it will not be available until 1997 at the earliest. All of the U.S. progress in high energy physics for the next decade must then come from non-SSC experiments. That has been recognized by my predecessors today.

The DOE budget submission for fiscal 1989 does contain sufficient funds to operate the new machines at SLAC and Fermilab and to operate a reasonable program at our other facilities.

I very much hope that this Committee will endorse the fiscal 1989 request so that we can produce the physics results that are the justification for the existence of our laboratories.

Thank you.

[The prepared statement of Dr. Richter follows:]

TESTIMONY BEFORE THE HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY; ENERGY RESEARCH AND DEVELOPMENT SUBCOMMITTEE

March 30, 1988

Burton Richter
Director, Stanford Linear Accelerator Center

I. INTRODUCTION

Madame Chairman, members of the Committee, I appreciate the opportunity to appear before you again. I have been asked to testify about the program of the Stanford Linear Accelerator Center (SLAC), emphasizing the accomplishments of this fiscal year, our projected activities in FY89 and our thoughts about the future program needs at SLAC.

SLAC is the world's highest energy electron accelerator. Our experiments mainly study the interaction of electrons and positrons, matter and antimatter, which can annihilate to produce new states of matter. Experiments at electron accelerators like SLAC and proton accelerators like Fermilab provide largely complementary methods of studying the ultimate structure of matter and the forces of nature.

SLAC is a national facility; its machines are used by some 600 scientists who come from more than 50 U.S. universities and laboratories, and from many foreign countries. FY1987 was a bad year for all of the users at SLAC because budgetary stringencies forced us to stop the High Energy Physics research program on our storage rings and to slow the pace of the commissioning of our newest accelerator, the SLAC Linear Collider (SLC). FY88 should see the beginning of research on our newest machine, and the start-up again of research on our storage rings. The FY89 budget submission, if approved, will allow us to attain a more reasonable level of operation.

I now turn to the status of our programs and the implications of the FY89 budget submission.

II. SLC

The SLAC Linear Collider is an innovation in accelerator design which has the potential to be much more cost-effective at very high energies than the almost thirty year old electron-positron colliding-beam storage ring technique. The key to the success of this new technique is not only to attain the required energy efficiently but also to produce extremely small beam spots at the collision point (hundreds of times smaller than in an equivalent storage ring) so that the reaction rate, as well as the energy, is sufficient to study the kinds of physics that one is interested in.

The construction of the SLC was completed in April of 1987, and the first phase of commissioning began then and lasted until early October 1987. We learned a great deal about this new kind of machine during that time. Much of the commissioning went as we expected; some parts were easier than expected; and some parts were more difficult. Our most pleasant surprise was the behavior of the very high power radiofrequency sources required to accelerate the beam to full energy. These klystron tubes, originally designed to produce 50 megawatts at peak power, happily run at 65 megawatts, and thus allow us to reach energies 15–20% above the original design energy if so desired for scientific reasons. Our most unpleasant surprise was the behavior of the very strong focusing magnetic guidefield that brings beams from the end of the linear accelerator to the collision point. The nonplanar nature of these two one-mile-long strings of very strong magnets caused the size of the beams to grow as they progressed through the strings. This problem has now been understood and brought under control.

After the completion of the first commissioning run, we spent a few months modifying and improving the most troublesome parts of the new facility, then began our second run in January of 1988 with the detector to be used in the first physics experiments in place. This detector (Mark II) is an upgrade of an existing device that was formerly used on our larger storage ring, PEP. While not designed for SLC energies, it will do very well for the first few years of experiments. This second running cycle was designed to lead smoothly from commissioning the machine into the first physics data-taking run.

One very important problem that had to be addressed was the sources of background that might give unwanted stray particles in the detector and so mask the real events generated at the collision point. We are currently spending about 15% of our running time studying the sources of these backgrounds, and in the last month we have brought the level down to the point where background will not interfere with the first experiments at our initial operating intensity. There is still more to do, but these first background tests have shown us where to put our efforts so as to reduce the backgrounds still further.

The electron beam spot is now down to a four-micron radius (a little more than one-ten thousandth of an inch). The positron beam intensity is sufficient for the first experiments. We now expect to begin the first data-taking run sometime in May, and we hope for the first results in time for the biannual International Conference on High Energy Physics which will be held in August. I have included as an appendix to this testimony a brief summary of the physics goals from the first round of experiments, written by Professor Jonathan Dorfan who is one of the spokesmen for the Mark II collaboration.

In parallel with our effort at SLAC, our European colleagues at CERN are rushing to complete the world's largest electron storage ring, the 27-kilometer circumference LEP project. The tunnel for this giant machine is complete, and the ring is scheduled to be ready to receive its first beam for full injection trials in the summer of 1989. Since storage-ring technology is much more familiar and thus better understood than linear-collider technology, I expect that their commissioning program will be somewhat shorter than ours, and they should begin experimental physics early in 1990.

III. STORAGE RINGS

We have two electron-positron colliding-beam storage rings at SLAC. Each of these machines is unique in the world in the sense that there are no others that operate in their energy ranges. (For technical reasons, colliding-beam storage rings can only operate effectively in a limited energy range.) Neither of our storage rings has operated for high energy physics since FY86 because of budgetary limitations, but we intend to resume the research programs at both rings in FY88.

The smaller of our two storage rings is the SPEAR facility. This is a 220-meter circumference ring that operates in the three to seven GeV energy range (center-of-mass energy). The energy range from three to five GeV is particularly rich, which accounts for the great longevity of this facility that first began operations for research in 1972. No major improvements in this facility have been made recently, although we expect the interaction rate to increase slowly over time through a series of small incremental improvements. Our Chinese colleagues are building a modern version of the SPEAR storage ring at the Institute of High Energy Physics in Beijing. We have been assisting them with both the machine and the detector under the US/PRC agreement for cooperation in high energy physics. They have achieved a first coasting beam (four turns) last December, and we look forward to having some competition in this energy range in a couple of years.

The PEP storage ring is a 2.3-kilometer circumference machine that runs in the 20 to 30 GeV region and that first began operating in 1980. We have recently completed an improvement to this facility which should increase the data rate by a factor of three to five. Single beam tests of the modified ring were made last December, and all seems well. We have also made improvements to the TPC, the major detector facility for PEP, that will allow the experimenters to use the higher luminosity more effectively.

The SPEAR and PEP facilities are both of great interest to the synchrotron radiation research user community. The SPEAR ring is shared equally with the Stanford Synchrotron Radiation Laboratory (SSRL), which supports a large and diversified program that spans the full spectrum of research from medical research to solid-state physics. The first tests of the PEP storage ring as a synchrotron light source have taken place, and in the parasitic mode where the operating conditions are set for high energy physics this facility is the brightest x-ray source available in the world by about a factor of ten. Tests in a dedicated synchrotron radiation mode took place last December, and PEP is even more effective in this configuration. Synchrotron light operations are funded by Basic Energy Sciences in the Department of Energy on a full cost-recovery basis for dedicated time, and the budget allocation that SSRL receives will determine how much of the available running time they can in fact use.

IV. BUDGETS

A. Operations

The FY89 budget request for operations is presented in a new form dividing the operations budget into two parts — Basic Research User Facility (BRUF) support, and General Science and Research (GSR) support. This new presentation is an attempt to give a better idea of how funds are divided between the facilities that support many diverse users and those things that support the science and research program using a facility at a particular institution. This new format should be useful to you in balancing funds for high energy physics, but I should note there is some ambiguity in the separation, and also that the two categories are clearly linked, at least for the existing program. The proper exploitation of our high energy physics facilities requires a balance between support of facility operations and support of research. It doesn't make sense to give lots of money to research and not have enough left to support the accelerator operations where the research is done, nor conversely to support operations very well and not give sufficient funds to support the research for which the facilities are operated. The balance proposed for FY89 is a reasonable one.

The operating budget proposed for SLAC for fiscal year 1989 totals $110.2 million, divided into $90.8 million for BRUF and $19.4 million for GSR. This is to be compared with a FY88 operations budget totaling $97.8 million divided roughly into $79 million for BRUF and $18.8 million for GSR.

These proposed FY89 operating funds would provide enough money to cover inflation and increased costs for such things as power, maintenance, spare parts, etc., that go with the higher level of accelerator operations we plan for next year. We will run the SLC for 30–32 weeks at high repetition rate, compared to only 13 weeks of such operation to be carried out in FY88. Our colliding-beam storage rings, PEP and SPEAR, will run in parallel with SLC operations in FY89. However, we do not expect to see a full effective 30 weeks of the storage ring operation since the SLC will have priority, and storage ring filling is likely to be less efficient than it will eventually be after we have fully developed a "quick switch" capability of going between the SLC mode and storage ring injection.

The GSR operations budget category is up by an amount that is slightly less than inflation. However, there will be a decrease in detector R&D associated with the SLD project (see section on Equipment) and a corresponding increase in the support for physics research in consequence of the increased level of accelerator operation that is planned for FY89.

B. Equipment

Equipment funds proposed in the President's FY89 budget submission total $22.7 million, as compared to $18.0 million in our FY88 Financial Plan. In FY89, as in the previous two fiscal years, we plan to put most of our equipment resources into items associated with the SLC. This includes the SLD detector, the polarized beam project, and the superconducting final focus system. The polarized beams and superconducting final focus system enhance the capabilities of the SLC itself. Polarized beams give us a unique capability to carry out physics experiments that are not possible with unpolarized beams like those that exist now at the SLC or will exist at LEP. The superconducting final focus system gives an enhancement of luminosity by approximately 50%.

The SLD detector is our single largest item. This detector is designed to match the physics opportunities available with the 100 GeV colliding beams attainable at the SLC. It includes a sophisticated set of calorimeters to measure the energies of both hadrons and electrons, a particle identification system and a superior particle tracking system, and a state-of-the-art vertex detector. This combination of elements will give it capabilities far beyond those of the Mark II detector and gives us an experimental facility that is a match to the potential of the machine and to the capabilities of the new generation of detectors being built for the LEP project at CERN. The SLD project is going extremely well, and now is paced entirely by the availability of financial resources rather than by technical considerations. With the equipment budget proposed for FY89 it looks like we can finish this project in FY90.

C. Accelerator Improvements

I have been asked to comment specifically on the Accelerator Improvement fund allocation for SLAC. I can start with a general observation. The replacement cost for the SLAC accelerators and storage rings, excluding laboratory buildings and accelerator housings, is roughly $300 million at today's prices. Our Accelerator Improvement allocation proposed for FY89 is $3.25 million, only a bit more than one percent of the present valuation of our machines. These funds go to modernize and improve the accelerators, and even the stony-hearted Internal Revenue Service would recognize that such a low rate of investment in the technical facilities of a major corporation is surely not excessive. (Note that the situation with respect to General Plant Project funding for our conventional facilities is similar.)

We have a large backlog of AI projects on our candidate list. These range from the replacement of very old systems to improve reliability and maintainability (our 25-year-old laser alignment system, for example) to the installation of improved versions of systems that have turned out to be not quite good enough for full SLC operations (our high powered positron production target, for example). For the next several years our AI funds will be devoted mainly to items that most *directly* affect SLC performance or operational reliability. Highest on our priority list are improvements to the damping rings, improvements affecting linac stability, control system modernization and enhancements, and improvements to the magnetic guidefield that brings beams from the end of the linac to the collision point. Many more things are needed, including improvements to the storage rings, but items which are merely important will have to wait until those that are vital to full performance of the SLC are accomplished. I hope that we can see an increase in AI funds in future years so that we can cut down the backlog of work to be done.

V. FUTURE PROGRAM

SLAC now has three main accelerator facilities functioning — the new SLC, and the two older storage rings. The SLC is opening up a new energy region to experimentation in high energy physics, and with its capability for polarized beams and vertex detection that takes advantage of the very small beam size will probably remain a frontier facility for the next decade, and a highly productive facility for a considerable time beyond that. Our two storage rings, while not on the energy frontier, have the potential for a great deal of highly productive research if we can support them. It should also be noted in thinking about the storage rings than it has often been the case in [illegible] that precision work at machines not at the energy frontier has led to great [illegible] in our understanding of physics.

To properly exploit these machines we should [illegible]heir operation up to the practical maximum. For the SLC this would be [illegible] weeks per year, a 25% increase over the projected level for FY88. The [illegible] of the time would be required for maintenance, modification and impro[illegible]. The storage rings can be operated in parallel with the SLC, and if we [illegible] some problems of SLC interaction with the storage ring injection require[illegible]ould be operated up to 40 weeks per year. It is difficult to estimate with [illegible] the increase in funding required for this level of operation, but I think [illegible] roughly require a 15% real growth in both the HEP and CER accounts [illegible]gories to support both the increased level of accelerator operation and [illegible]ase in physics research that would go with it.

SLAC will also need a major upgrade in its c[illegible]ng facilities in the near future. In FY88 the presently installed computer [illegible] will be inadequate to handle the data coming in even at the FY88 le[illegible]perations. We have requested a major upgrade in computing facilities [illegible]Y89 budget, and I hope it will be included in the next budget submission.

In the Accelerator R&D area we are actively e[illegible]n the study of advanced linear colliders with the aim of developing the tec[illegible] base to allow the construction of a TeV-scale electron-positron linear c[illegible]at an appropriate time. A linear collider of this energy must also operate [illegible]much higher luminosity than the SLC, and so requires the development of [illegible]fective accelerators and of power sources. We have begun a collaboration [illegible]he Lawrence Livermore National Laboratory in the power-source area wh[illegible]ws great promise. This work marries the technology of Livermore's indu[illegible]ccelerators with our rf technology and aims at producing power sources [illegible] of operating at the gigawatt (billion watt) level. In addition, we are in[illegible] the study of new types of accelerating structures and in an intense the[illegible]tudy of the production of very small beams and the focusing of such bea[illegible]pots which are a factor of 100 smaller than those realized at the SLC.

There is an expanding international interes[illegible]vanced linear colliders. SLAC is clearly the leader in this field (after al[illegible]ve built one), but Europe, Japan and the Soviet Union are becoming [illegible]eavily involved in this work. There is a great deal to do, and we are try[illegible]ernationalize the R&D program so that each of the regions can tackle par[illegible] problem to the benefit of all. Toward this end we are organizing a worksh[illegible]advanced linear colliders to be held at SLAC near the end of this year [illegible] will bring together all of the groups most interested in this work to evaluate where we are and to try to develop a coordinated R&D program to be carried out in the several areas. Considering where we are now and how much is still to be done, I think it will be some time around 1992 before a sensible proposal with believable costs could be prepared.

We are also examining the possibilities for intermediate-sized projects with energies ranging from those of the present storage rings to the energy of the SLC but with luminosities a factor of 100 to 1000 times higher than present machines. There are both technical issues (how to build them) and physics issues (should we build them) that have to be addressed before one can come to a decision on whether to press for the construction of one of these intermediate-scale projects.

You will be hearing from us in a few years.

CONCLUSION

FY88 and FY89 should be particularly exciting years in the U.S. High Energy Physics program. The two premier accelerator physics facilities in the world, the SLC at SLAC and the Tevatron collider at Fermilab, will begin to produce the physics results that will justify the funds spent on their construction. The realization of the vast potential of these facilities requires sufficient funding to operate the machines and to support their experimental programs. The storage rings at SLAC, the fixed-target program at FNAL, and the high-intensity low-energy beams at BNL, while not at the energy frontier, are potentially very productive and their capabilities are not duplicated by any other facility in the world. These important facilities should also be supported at an adequate level to maintain the breadth of the U.S. High Energy Physics program. The DOE budget request also includes funds for experiments at various foreign facilities (CERN, DESY, KEK), and here too there is important work to be done at facilities that are not duplicated here.

What is surely on many people's minds in this budget year is the Superconducting Super Collider (SSC), and the impact that this project will have on the rest of science. I think it is worthwhile to repeat something I said at these hearings last year. The SSC will be a magnificent research tool when completed, but because of its size and its cost will not be available until 1997 at the earliest. All of the progress in High Energy Physics for the next decade must then come from non-SSC experiments. Thus, even during SSC construction, sufficient funds must be provided to carry out a full program at the existing laboratories if the U.S. High Energy Physics enterprise is to remain productive.

The DOE budget submission for FY89 does contain sufficient funds to operate the new machines at SLAC and FNAL and to operate a reasonable program at our other facilities. I very much hope that this committee will endorse the FY89 request so that we can produce the physics results that are the justification for the existence of our laboratories.

Appendix 1

February 1988

A Brief Summary of the Physics Program of the SLC

Jonathan Dorfan

The interactions in Nature are governed by four fundamental forces – Strong, Weak, Electromagnetic and Gravity. Particle physics is primarily concerned with the study of the first three forces, although with the increased effort in the area of unification, theoretical particle physicists are increasingly concerned with all four. The aim of this write-up is to relate our present theoretical understanding of particle physics to the measurements which will be performed at the SLC; in this context we will ignore gravity.

The present status of our theoretical understanding of the Strong, Weak and Electromagnetic forces is summarized by what has become known as the Standard Model. Enormous progress in the last twenty years has resulted in this model which, to date, can explain all verified and well established experimental measurements. Whether these measurements pertain to the Strong, Weak or Electromagnetic force, there exists no conflict with the predictions of the theory. The three forces, which twenty years ago seemed so unrelated, are now all couched in a remarkably similar form; indeed the Weak and Electromagnetic interactions are unified into the Electroweak interaction. Each force is *mediated* by a bosonic particle(s) (particle of spin 1) which is to say we envisage an interaction as resulting from the emission and re-absorption of the bosonic carrier of the force. The particles upon which the forces act are relatively few in number (12) and are all fermions (have spin $\frac{1}{2}$). These constituent particles, shown in the attached Table 1, are divided into two species, leptons and quarks.

The six leptons comprise the electron and its neutrino, the muon and its neutrino and the tau and its neutrino. The leptons participate in the Electromagnetic and Weak interactions, but not in the Strong interaction. The notion of the *electric* charge of a particle is well known to you all. The uniformity of the three interactions alluded to above assigns to all these particles analogous properties of *weak* charge and *color* (strong) charge. Just as particles which have no electric charge are impervious to the effects of the electromagnetic interaction, leptons have no color charge and are thus impervious to the color (strong) interaction.

The quarks are the fundamental constituents of hadronic matter (protons, neutrons, pions, etc.) and come in six flavors, namely up, down, strange, charm, bottom and top. They carry electric, weak and color charge and therefore participate in all of the three basic interactions.

Also shown in Table 1 are the force carriers: the massless photon which mediates the electromagnetic interaction and therefore "couples" to electric charge, the massive $W^{\pm}$ and Z^{o} which mediate the weak interaction and couple to weak charge, and the 8 massless gluons which mediate the color (strong) force and couple to color charge, namely to quarks. We refer to the leptons and quarks as *constituents* because they represent the most basic (smallest) particles which are observed in Nature. From measurements we know that they have no internal structure down to the level of $10^{-16} cm$.

We notice the very beautiful symmetry between the quarks and the leptons, namely there are six of each. The symmetry is even more striking in that the six members of each group break up into three distinct subgroups or *generations* as they are called. The members of the three generations (see Table 1) are, respectively, the electron, its neutrino and the up and down quarks; the muon, its neutrino and the strange and charm quarks; and the tau, its neutrino and the bottom and top quarks. The two distinguishing features of the generations are that (1) the electrically charged members are increasingly heavier in increasingly higher generations, and (2) each generation has one massless, electrically neutral neutrino. We notice a curiosity here – the universe which we know and love is comprised of objects built solely out of first generation particles. The Standard Model offers no explanation for the peculiar replication of this lowest generation, nor does it tell us how many generations there are in Nature. That there are only three generations is an empirical fact, and a crucial piece of experimental data needed is a precise measurement of the number of generations in the world. The SLC will provide just such a measurement.

We have omitted one major ingredient in the particle spectrum of the Standard Model – the neutral Higgs Particle. If one writes down the equations of the Standard Model in the most fundamental form, one finds that the symmetry of the theory implies that all particles, including the force carriers, are massless. Since this is contrary to empirical fact, an extra ingredient must be added to the Standard Model. The so-called Higgs mechanism is used to generate a spontaneous symmetry breaking which results in the generation of mass for the $W^{\pm}$, Z^{o}, the quarks and leptons. In addition one new physical particle, the neutral Higgs, results. (This is the so-called minimal Model; it is also possible to have non-minimal models which then produce more physical Higgs particles including charged Higgs.) Unfortunately, as with all other particles, the mass of the H^{o} is not predicted by the model although it cannot be heavier than about 1 TeV. The presence of at least one Higgs particle is a crucial ingredient for the Standard Model. Since no Higgs has ever been seen, its discovery would be a great experimental triumph. The only other unconfirmed particle in the Standard Model spectrum is the top quark.

Thus far we have described the Standard Model in glowing terms. As an edifice for our understanding of phenomena at the energies probed so far it is indeed a magnificent success. However, as an ultimate model of the world it has significant shortcomings, and the common lore is that it is an excellent low energy approximation to the ultimate model, much in the way that Newtonian mechanics gave an excellent low energy description of relativistic mechanics. What are the problems with the Standard Model? For one, all the interactions are not unified. In addition, there are too many (18) parameters in the model, numbers which must be put in by hand which one would expect the ultimate theory to provide. The model doesn't explain the origin of the generations nor how many there should be. The mechanism of mass generation discussed above is very ad hoc (unnatural) and it requires incredibly fine tuning to work. It would be most strange if Nature accomplished its goals in this most unnatural way. So there are competing theories which try to overcome these deficiencies, in particular the unnaturalness of the Higgs mechanism. Two such theories are Supersymmetry (SUSY) and Techni-color. These theories have more natural mechanisms for mass generation – they achieve this at a price of more fundamental constituent particles. In the case of SUSY, in fact, a doubling of the number of constituents. Physical Higgs particles are also predicted in these theories, in both cases both charged and neutral. These issues of the extension of the Standard Model to obviate the mass hierarchy problem (as it is known) are not mere paper exercises but important theoretical alternatives. Experimental verification of the particle spectrum from these theories would be a significant breakthrough.

We are now in a position to understand what can be learned from the SLC. At the SLC we will collide electrons and positrons at an energy tuned to the physical mass of the Z^o. In this case the beams annihilate to produce a Z^o which will rapidly decay. The Z^o is the carrier of the weak force and hence from our previous discussion it can decay into pairs of particles (in almost all cases the particle and its anti-particle) which carry *weak* charge. But, all particles carry weak charge, and hence, all particles which have a mass less than half the mass of the Z^o are produced (see fig. attached). The Z^o provides a window to all physics which lies below its mass scale, and in this sense is a laboratory for the study of high energy physics of unprecedented richness. No other facility yet built can boast this property.

The Z^o is a so-called resonance which is specified by two important parameters – its mass and its width. A resonance can be thought of as a bell-shaped curve where the peak of the curve corresponds to the mass, and the half width at the half height of the curve corresponds to the width. The width of a particle resonance is a direct measure of the number of final states which the resonance can decay into. The more final states, the larger the width. The Z^o resonance shape can be mapped out by successively changing the energy of the SLC machine and "scanning" across the Z^o. If the Z^o width is seen to be larger than the prediction of the Standard Model, we *immediately* know that there must be some new physics which goes beyond the Standard Model. One of the aims of the SLC physics program is to make precise tests of the Standard Model via very precise measurements of the Z^o mass and width. At present the Z^o mass is known to a precision of 1.7 GeV; at the SLC it will be measured 40 times more precisely. This measurement then fixes the decay branching fraction predictions for all the final states as well as the strength of the coupling of the Z^o to all the fundamental quarks and leptons. Measurements of these quantities will then constitute precision tests of the Standard Model. If the model is not correct at this level of precision, inconsistencies will show up in these measurements.

The top quark will easily be found if it has a mass less than half the Z^o mass. The elusive Higgs particle, H^o, can be found if it has a mass less than 40 GeV; charged Higgs will be found up to masses of 45 GeV. If there is a 4th generation of quarks and leptons, they too can be discovered. If one of the quarks or charged leptons of this 4th generation has a mass less than half the Z^o mass, it will be discovered thereby signalling a new generation. However, these particles may well be too heavy to produce. In this case one is left with seeing the 4th generation via its massless neutrino (ν). In a more general sense we may ask, can we count the number of generations in the world at SLC? For this we return to the measurement of the width. Even though we cannot detect the decay $Z^o \rightarrow \nu\bar{\nu}$ *directly* in our detectors, it will contribute to the Z^o width. Each generation contributes 160 MeV to the Z^o width via this channel. A precise measurement of the Z^o width provides essential input about the number of ν species, and hence, the number of generations. At the SLC we expect to measure the Z^o width to about 35 MeV, less than 1/4 of the increase due to one generation. As a second round experiment, one that will require the full design luminosity of the SLC, a more direct method can be used to count the number of the ν species. It should have a potential for measuring this fundamental quantity to better than 1/5 of a ν species and thereby clearly distinguish between 3 and 4 generations.

If SUSY or Techni-color particles have masses less than half the Z° mass or if the charged Higgs have masses in the same range, the SLC would be able to find them. The SLC thus has sensitivity to the Models which goes beyond the Standard Model.

In summary the physics of the SLC creates enormous excitement because of the tremendous potential for probing nature. It will provide unprecedented precision tests of our present theoretical understanding of the world, and perhaps under such close scrutiny new physics will evolve. The SLC will permit us to study most of the leading questions of particle physics. If the top quark has a mass of less than 45 GeV/c^2 it is easily discovered; if the neutral Higgs particle has a mass of less than 40 GeV/c^2 it can be discovered. The number of fundamental generations in the world will be measured to sufficient precision to say what this quantity is with a certainty significantly smaller than one generation. If a fourth generation exists and its quarks and leptons have masses below 45 GeV/c^2, they too will be discovered. Theories which go beyond the Standard Model, like Supersymmetry or Techni-color, can be tested if the additional fundamental constituents which they predict lie below 45 GeV/c^2.

We should also not forget that, even in the absence of new breakthroughs or major discoveries, the SLC provides a laboratory for the study of particle physics of unprecedented richness. All the known constituents are produced in pairs and can be studied in a high statistics, clean environment. This will contribute significantly to our present knowledge of the properties of the fundamental particle spectrum.

Table 1. The Particles of the Standard Model

Leptons:

Name	Symbol	Mass(GeV)	Electric Charge
electron	e^-	.000511	-1
electron neutrino	ν_e	0	0
muon	μ^-	.106	-1
muon neutrino	ν_μ	0	0
tau	τ^-	1.784	-1
tau neutrino	ν_τ	0	0

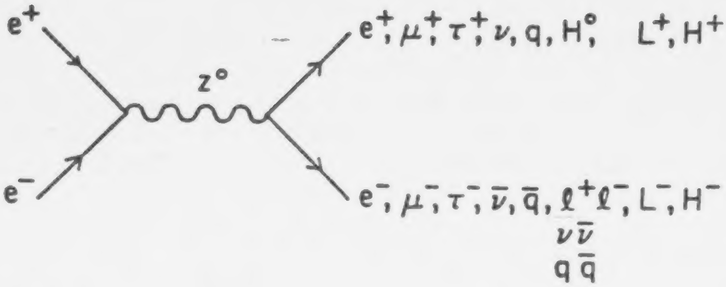
Quarks:

Name	Symbol	Mass(GeV)	Electric Charge
up	u	.31	$+\frac{2}{3}$
down	d	.31	$-\frac{1}{3}$
charm	c	1.50	$+\frac{2}{3}$
strange	s	.51	$-\frac{1}{3}$
top	t	$> 23.$	$+\frac{2}{3}$
bottom	b	5.0	$-\frac{1}{3}$

Carriers of Force:

Force(Carrier)	Symbol	Mass(GeV)	Electric Charge
Electromagnetism (photon)	γ	0	0
Weak (weak vector bosons)	Z^0	92.	0
	W^+	82.	$+1$
	W^-	82.	-1
Strong(gluon)	g	0	0

Higgs: H^0


e^+
e^-
Z°
$e^+, \mu^+, \tau^+, \nu, q, H^\circ, \quad L^+, H^+$
$e^-, \mu^-, \tau^-, \bar{\nu}, \bar{q}, \ell^+\ell^-, L^-, H^-$
$\nu\bar{\nu}$
$q\bar{q}$

This figure shows the production and subsequent decay of a Z^o in electron-positron collisions. Most of the possible decay channels available to the Z^o are shown and are typically the decay to a particle and its anti- particle. The decay channel shown in the figure are respectively electron-positron, muon anti-muon, tau anti-tau, neutrino anti-neutrino, quark anti-quark, neutral Higgs fermion anti-fermion (where the fermion can be a lepton, neutrino or quark), 4th generation charged lepton anti-lepton, and charged Higgs anti-Higgs. All of these possible decay modes of the Z^o have clear and distinctive signatures for their study.

PANEL 2 DISCUSSION

Mr. **Chapman**. I would like to thank both of you for your testimony and your comments and let me begin by saying that what I hear, reading your testimony and having watched just in my brief time on this Committee the evolution of the business you are about, that this is indeed exciting times in the world of science, particularly in the world of high energy physics.

Getting back down to the realities of dollars, certainly I don't think you would have any problem at all with this Committee supporting the budget request of the Department of Energy. The realities are we are not likely to get those numbers. The question becomes one of how do we enhance your work in budget times that the Congress is not going in all probability to fund the full request.

What do we do? Where do we squeeze? Where do we tighten the belt?

It is my judgment that all of the things that you have said here today, and this is just one Member's opinion, and over and over we hear that the basic continuing science programs are at the point now that results are going to be seen, you have improvements programmed and program developments at your facilities that for the next decade appear to offer tremendous promise in research. Out there is SSC, which is the next generation and the next step a decade or so away.

We sit here and recognize as Members of this Committee, we are very unlikely to be able to see this kind of aggressive scientific program to our colleagues in Congress until we can build either greater knowledge or a constituency for what you are about.

With all that, in light of the budget numbers as are now contained in the House Budget Resolution, where do we go without sacrificing the important work you are doing, where do we go to find the cuts that are going to be necessary? How much can we reduce that SSC budget and still maintain a meaningful program, what is the absolute minimum amount necessary in FY 1989 for SSC?

Dr. Lederman, I know you have been involved in this from its embryonic state and the planning, and I know you both are strong proponents as are we of the project.

How do we handle it? We are here and you testified in support of the Department of Energy's budget request, yet the House has already moved with some indication that we are not going to get those figures. What do we do next? What is the amount we can take, if we are going to have to take a hit, where do we take it?

Dr. **Lederman**. Is this the easy question, sir? [Laughter.]

Mr. **Chapman**. This is the one I want you to answer for those of us who will have to fill in the blanks on the numbers over in the Appropriations Committee.

Dr. **Lederman**. In general, the question is above my salary level. [Laughter.]

I do think they are important questions. As far as SSC's minimum cost, I really can't give you a sharp answer because I'm not really in touch with the details of the upcoming costs. Informally and being aware of that progress and in the R&D part of the program especially, I would think the request for R&D funds, that part of the President's request for R&D funds, is the most important part of that. I remember that being something like $80 million with other parts of the R&D adding to that, at the level of $100 million.

I always thought the program could get a very good start with about that level of R&D funds and perhaps as mentioned, a certain amount of long lead time items, which might add up to $150 million. I think that would be a good first start on the project. I think from everything I can see, that would yield a successful R&D program which has gotten a lot of momentum in the last six months.

Whereas I am not officially capable of giving a quantitative answer, my own personal opinion is at the level of roughly $150 million, the project would be healthy.

Mr. CHAPMAN. If we set that as the number or that ballpark as the number, where does that leave you, you two gentlemen, with the work you are doing at your facilities? Assume we come down somewhere in the ballpark, perhaps a slight increase, a compromise with the Senate, the growth that you need at your facilities, the programs, the projects, experiments you have planned, if SSC is funded at the approximately $150 million?

Dr. LEDERMAN. This is really the Budget Committee's ceiling?

Mr. CHAPMAN. Yes.

Dr. LEDERMAN. I think that will be very tough. I think the budget ceiling, what we are really hoping is the budget ceiling flexes a little bit, percentage-wise, it wouldn't be much of a stretch to accommodate this, we are close in that sense, I think. I think both of us are in the situation where as we pointed out, we have an enormous urgency to actually collect data, to actually produce physics for the enormous sums of money that are being spent in high energy physics. This is a long investment. We have been in ten years of building and now we want to actually operate. I think squeezing into that particular ceiling would be extremely tight.

Dr. LATHROP. That would be at the expense of our capabilities, if we had to fit into that ceiling. It would cause us to cut back from what we actually could do.

Mr. CHAPMAN. Like a manufacturing plant, you would be operating at a lot less than 100-percent capacity, if those budget constraints remain?

Dr. LATHROP. Indeed. For us, it should be a particularly exciting time and we hope it is ahead of the LEP conventional technology machine that is going to be in our same energy range in fiscal 1990. That might delay that.

Mr. CHAPMAN. Give us an opinion if you can both of you, what kind of growth you need in your budgets, to continue the operating for 1989, 1990, 1991, what kind of growth do you foresee since you are in that point now with data acquisition, actual experimentation, the new computers and computer time you need to assimilate the data. What do you see up the road as the growth, in trying to fit where we are going from here? What you will need just for your operations.

Dr. LATHROP. Next year, the President's budget submission is adequate for us at SLAC. In fiscal 1990, we would need 15-percent real growth from that.

Mr. CHAPMAN. Dr. Lederman?

Dr. **Lederman**. Again, I tend to agree that we are close in the 1989 budget to what we need. We would like to argue that the DOE may have a little bit of extra cash that has not been allocated yet, and we will fight for that, and not disturb the Congress with it, with those issues.

In 1990, there is where we would like to see in operating, since we are operating, we would like to see a little relief from the inflation increase we got this year in order to take up these deferred maintenance and spares and make sure we have some reliability in our operation. That would require something like an 8-percent increase, 3 percent over inflation, in the operating plus equipment category. It is in the line item category where we have most recently gone down after finishing the Tevatron, that we would like to keep a level that will enable us to maintain and improve the facility.

As we pointed out, this kind of facility really requires—it is like riding on a tiger, you don't want to get off. It requires some modest improvements every year in order to make the physics continue. That is where we thought if you take it as a percentage basis, it is about a 10-percent increase for the construction phase.

Mr. **Chapman**. And 10-percent real increase or 10 percent would include the inflationary factor?

Dr. **Lederman**. It's a new item so I think it would be a real increase in that sense.

Mr. **Chapman**. All right. Mr. Fawell?

Mr. **Fawell**. Thank you, Mr. Chairman.

Dr. Lederman, in your testimony, you referred to, in reference to the 1989 budget, the need to complete the D-Zero detector as well as the deferred maintenance that you are sustaining and collider upgrading, as I recall.

What will be the gap in fiscal year 1989 between the level of operation that you can achieve with the proposed Department of Energy allocation and the optimal level of operation, and how much funding would it take to close this gap?

Dr. **Lederman**. Let me try to explain that. As I pointed out, we give highest priority to operation and we think that is so important that it deserves the highest priority. Our determination in 1989 is to operate as best we can, therefore, what we do is we forego the R&D parts of the operating budget and we forego the maintenance parts of the operating budget in order to give a priority to the operations.

All we will say is we will operate in 1989, hopefully, 52 weeks around the clock, as much as possible to get the data out, but we would be greatly relieved if we had two or three percent over inflation in order to begin to address some of these deferred maintenance needs and spares needs that I am sure will bite us at some point.

As far as the D-Zero, there we are short about $3 million in the equipment category and we intend to do battle with the Department of Energy in order to see if they can rearrange their allocations to take it away from SLAC or some other of our friends.

Mr. **Fawell**. That has been indicated. I know you know I am a great proponent of the SSC. I think it ought to be done. Yet, we are all in that tight situation where we want the optimal operations and we have all indicated, as has the President, that the SSC ought not to collide, if I can use a pun there, with the optimal operations. It is a bit of a sticky wicket, I guess. Would you not agree?

Dr. Lederman. I certainly agree. Our timing couldn't have been worse in plunging into this great adventure of the SSC. On the other hand, the timing is dictated by the science and by the opportunities and certainly having the SSC in 1997 or 1998 will be appropriate, since the last machines would have been built a decade before.

Mr. Fawell. It is frustrating to see two tremendously exciting frontiers and not be able to do everything that you would want to do.

Let me ask this question: You had referred in your testimony to international contributions which have been made insofar as the Tevatron is concerned. In regard to the building of Fermi and the added capital construction costs, what percentage has come from foreign international contributions?

Dr. Lederman. Mr. Fawell, in the construction of the Fermilab, that was done entirely by the U.S. Government. At that time, there was not enough perhaps forethought or imagination perhaps to get international collaboration in construction. There has always been international collaboration in the building of detectors.

In fact, one of the first experiments done at Fermilab was done by a Soviet group that brought their own very fancy, very sophisticated equipment to the laboratory to carry out some experiments. Since then, Western Europe, the Soviets, even the Chinese have been participating in our research and on the average, I think they do contribute in the experimental detector applications at some level between 10 and 20 percent of our operating costs or equipment costs, that are provided by foreign contributions.

The idea of contributing collaboratively to the construction of the accelerator is a relatively new idea, which we hope will be pioneered by the SSC.

Mr. Fawell. It has been said that the SSC will be built but the question is where. If it were not constructed in the United States, in your opinion, where would it be built?

Dr. Lederman. If we sort of start over and look for a new site?

Mr. Fawell. Let's assume Congress in its wisdom is unable to come up with the funds or for some reason to fall short.

Dr. Lederman. That's an excellent question. It is almost mind boggling in its scope.

Mr. Fawell. Where no eyeball as heretofore has set foot.

Dr. Lederman. Yes. There is an International Committee on Future Accelerators, of which I was a founding member in 1975, which addressed the issue of the existence of a world laboratory, which would be this imaginative idea of all the nations in the world contributing proportionately to the creation of an accelerator and presumably other things that you might want to put there, perhaps a world university. It was very idealistic and we were very enthusiastic about this.

Somehow, in all of these negotiations between 1975 and onward, we never got down to being able to come to grips with this political issue but we did discuss locations, for example. One favorite location in 1975 in fact was Iran, because it was a nice stable government, a crossroads of commerce. [Laughter.]

There are hazards in all of this.

Mr. **Fawell**. I get your point. Any other stable areas that were contemplated? [Laughter.]

Dr. **Lederman**. We are open to suggestions.

Mr. **Fawell**. How much additional research funding would be required to support an optimal level of operations for fiscal 1989?

Dr. **Lederman**. As I said, our increase in fiscal 1989 was slightly under inflation. We are going to have a tough year and again we will forego many things in order to operate. Once upon a time, Fermilab had a conventional accelerator and we could always save money by turning it off and the power bills would accumulate and that is significant sums of money. Now we have a superconducting accelerator and you can't turn it off because you have to keep it cold and you always warm up a superconducting machine at great risk and peril to numerable problems that might occur. You like to keep it cold. Once you keep it cold, there is very little savings in not operating. We then say it is just ridiculous to have a machine that is cold and not operating. We don't save much so you might as well use it. We are driven by that economic factor to no longer say, if you don't give me enough money, I will not be able to operate. We have to operate.

It is taken out of the future options of the laboratory and out of the maintenance and out of the spares and so if we don't operate it will be because we are repairing something or manufacturing something that should have been on the shelf.

To answer the question, we thought that to operate comfortably, we would need about another 3 percent over the inflation. That would give us the comfort of being able to get on with the maintenance and breathe a little bit and to rebuild the sort of infrastructure that is weakening and beyond that, we have in fact requested additional R&D money to get on with the upgrade which would be an additional two or three percent.

We are at the level where we are talking about rather small percentages, although when you multiply them out, they really involve substantial sums of money.

Somehow I think we are in this almost absurd situation of being very close to good operation but missing it. As you may know, a large laboratory is very highly leveraged. The next one or two percent of our budget is very, very fruitful because you have so many fixed costs that you have to do postage and safety and answering all the DOE forms.

Mr. **Fawell**. I see Dr. Lathrop nodding his head.

Mr. **Lathrop**. I agree.

Mr. **Fawell**. I suppose the accelerator improvement fund could use more funds.

Mr. **Lathrop**. The accelerator improvement funds are essential to us. They are our life's blood. They give us the opportunity to improve the capability of the machine.

Mr. **Fawell**. Thank you very much. I have no further questions, Mr. Chairman.

Mr. **Chapman**. The gentleman from New York.

Mr. **Hochbrueckner**. No questions, Mr. Chairman.

Mr. **Chapman**. Gentlemen, let me ask one last question. We are running behind. Both of you I know are great proponents of the SSC and in the budget times that we find ourselves in, this is one of the things we are going to hear in the battle on the Floor of the House about the project.

What are the chances, assuming that Congress is unable to move as quickly as we would like, what are the chances that the technological developments in the superconducting materials will be such that a higher-temperature superconducting material could be developed, talking about where you could turn this thing off, if the cryogenics were such a critical part of it, if the cooling makes it work, if we develop a superconducting material that does not require that degree of cooling, is that not a likelihood in the next five to ten years and what does that do to the SSC?

Dr. **Lederman**. Sir, we have clearly been very interested in that aspect of it and have been following the developments very closely. In fact, in our laboratory, we actually have some specific R&D program looking at these new high-temperature materials. Our impression and confirmed by many groups of experts who have looked at this including experts in the field, working actively in the field of high-temperature superconductors, for example, Bardeen and Schrieffer, who both have Nobel Prizes, I think there are three between the two of them, and are prominent in the field of superconductivity, all agree that the distance between practical realization of these new materials into an accelerator format are many, many years away, almost an unpredictable number of years away.

There are two components of the difficulty. One is in bringing the materials up to the properties that you need for a magnet. That means large currents and high magnetic fields and the materials ductile enough to be able to wind in the magnets. All of these problems are very formidable and the estimates vary from 5 to 10 years in order to get to that stage. When you have gotten to that stage, you have another problem in trying to reduce the costs significantly, to reduce the cost significantly, you need much, much higher magnetic fields so you don't need a 50-mile circumference, you might want a 5-mile circumference.

This creates enormous forces which if you took that particular improvement, all known materials would flow, the hardest steels would flow under those forces. The engineering problems of being able to profit from the new materials again are mind boggling and some kids maybe now in grammar school will solve these problems, but we have no idea of how to do that.

Using the high-temperature superconductors in the formal method of building an accelerator now, just isn't in the cards. Something brand new that we can't visualize will have to come in before we can use these materials.

Mr. **Chapman**. Thank you, Dr. Lederman and Dr. Lathrop for being with us today.

[Questions and answers for the record follow:]

Fermilab

Responses to Questions for the Record
FY 1989 Authorization Request for General Sciences Programs
Subcommittee on Energy Research and Development

L. M. Lederman
Fermi National Accelerator Laboratory

1. Do you see a real possibility that funding to maintain an adequate program for the SSC could be obtained from the base program which is used to operate Fermilab and the SLAC facility?

I interpret the question to refer to the FY 1989 President's Budget Request. This allocated operating sums to Fermilab which would indeed allow us to operate the TEVATRON for over 80% of the available time in FY'89. The reason is that this has the highest priority in our activities and we are in a unique situation. A large laboratory prudently divides its resources between maintaining a healthy infrastructure, operating its facilities and investing in future capability. The latter includes improvements in the accelerators and associated beam lines, computer department and assistance to our users in building their equipment for research scheduled in FY90, 91, etc., and to various R&D activities designed to make the TEVATRON and its research more effective.

In the past several years we have emerged from a long period of TEVATRON construction and have placed operation as an overriding priority. Thus, we will run on machines and do research in FY89, stopping only for repairs and most urgent maintenance. The sums available for R&D, for improving machines, for infrastructure maintenance, etc. are in fact disappointing. However, in fairness, we were equally disappointed with our operating budget in FY88 when the SSC allocation was $25M instead of the requested $363M.

Thus, a literal response to the question is: no. There is no "fat" in the Fermilab operations budget. If we take the most optimistic view of what " ... adequate program for the SSC" is, say $150M in FY 1989, and allocated this from the Fermilab and SLAC base programs (which is a total of about $300M in FY89, the answer is that both labs would simply shut down.

If the question means: does SSC in FY89 cut into the base programs of Fermilab?, my response is that it probably did not impact on DOE's allocation of HEP budgets as between Fermilab, SLAC, BNL, the universities, etc. Obviously we believe that DOE does not allocate enough to Fermilab but this would seem to be independent of SSC funding, at least in '88 and '89.

If the question really looks to the entire SSC construction period, then obviously any significant contribution to the SSC construction by base program cuts at Fermilab and SLAC would seriously impact on physics output in the years 1990-1997-8 i.e. when SSC would really begin to produce science.

If, finally, the question refers to the operating phase of SSC then there is reason to look to Fermi and SLAC for contributions to SSC operating costs since it is part of the HEP tradition of supporting our most advanced facilities out of older facilities' budgets. It is obviously too early to predict how this should be done since the physics of the TEVATRON and SLC are not yet developed. We should also note that SLAC and Fermilab and their university users account for only about 70% of the HEP budget.

2. Has there been any discussion of this within the community?

Again, we are not sure which interpretation is relevant but there has indeed been much discussion of maintaining an adequate physics activity in the U.S. while awaiting SSC operation. We need to have research activity for the young scientists who are entering the field, we need to push on the detector developments which SSC will require and we need to enrich and strengthen the scientific base upon which SSC research stands.

However, in the post-SSC environment, it is the general view that the increases in the operating budgets for SSC can in part come from a shrinking of the other HEP activities. SSC, by itself, should not imply a substantial increase in base HEP operations.

3. Do you have any thoughts on " ... innovative ways of perhaps finding alternative methods to fund the important large science projects on a continuing basis?

One very innovative suggestion is to encourage the winning state in the SSC site contest to finance the SSC via a state bond issue of, say, $3 Billion. These bonds would be retired via agreement with the Congress by charging the U.S.DOE for the accelerated protons much as a utility charges for electricity. This would have the effect of removing construction bumps from the funding profile. These would be smoothed into higher operating costs since we'd now be paying for protons as well as operating costs of the lab. The effect would be to spread the construction costs over say 25 years of operation.

This has some obvious drawbacks and we believe the suggestion from the Subcommittee of a revolving fund i.e. an entitlement-style program for science funding, is a statesmanlike and visionary idea.

STANFORD UNIVERSITY

STANFORD LINEAR ACCELERATOR CENTER

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Stanford, CA 94305
(415) 854-3300

April 15, 1988

The Honorable Marilyn Lloyd, Chairman
Committee on Science, Space and Technology
Subcommittee on Energy Research & Development
Rayburn House Office Building, B-374
Washington, D.C. 20515

Dear Mrs. Lloyd:

I am responding to your letter of April 11, 1988 which contains a set of questions for the record of the hearing on the DOE FY89 General Sciences Program. For clarity I repeat the question below before its answer.

QUESTIONS FROM THE CHAIRMAN

1-a. *"Do you see a real possibility that funding to maintain an adequate program for the SSC could be obtained from the base program which is used to operate Fermilab and the SLAC facility?"*

Answer: No! The very name "base program" is a misnomer which I dislike intensely. If it were called something like "the physics program" it would be better described, for all of the physics results coming out in the next 8-10 years, even with maximum possible funding of the SSC will come from this "physics program." The program is barely adequately funded now and would be severely impacted by a cutback to support the construction of the SSC. I do not believe that we should proceed with the SSC at the cost of leaving unexploited the new facilities that we have just finished building, or at the cost of damaging other areas of science. But, I also believe that this country must be prepared to both support science now, and to build the facilities needed for the future if the U.S. basic research enterprise is to remain healthy for the long term.

1-b. *"Has there been any discussion of this within the community?"*

Answer: There has been discussion of this within the community and the consensus is, of course, that we should proceed both with the construction of the facility for the future, the SSC, and continue to exploit the new facilities just coming into operation. If the community were presented with a stark choice, I believe they would answer as I did.

2. *"Are there any remaining show stoppers that could cause problems in the operation of the SLC?"*

Answer: We do not believe that there are any, and we expect to start the physics research program in May. Something may turn up then, but we believe that to be unlikely.

3. *"It is my understanding that the budget request submitted to us by the Department for FY1989 would allow for approximately seven months of actual operating time for physics experiments on the Stanford Linear Collider. Is this correct?"*

Answer: This is almost correct. The budget allows for seven months total operating time of the SLC, and thus includes an allotment of 10–20% for accelerator studies and development.

4. *"What would be the nature of the physics that would be accomplished in FY89 if the proposed operating budgets were approved by Congress?"*

Answer: The appendix to my written testimony includes a discussion of the physics goals of the SLC. The achievement of all those goals will require many years of operation. In FY89 we expect to obtain approximately 10,000 Z^0 events. With this sample we expect to be able to obtain a high-precision measurement of the Z^0 mass, thus constraining deviations from the standard model of the weak interactions; to obtain a measurement of the Z^0 width sufficient to limit the number of possible new generations of low-mass neutrinos to ≤ 1; to obtain definitive answers to the question of the existence of the top quark, heavy leptons, and some other kinds of new particles with masses in our accessible energy range, and to look for "surprises" in Z^0 decay modes at the few percent level.

5. *"How would this compare with the physics experiments that would be accomplished on facilities at CERN and elsewhere in Europe, Japan or the Soviet Union?"*

Answer: No other electron-positron facility will be operating in the SLC energy range during FY89, and hence there is no competition. Some evidence on the existence of new particles may come from high-precision measurements at the CERN proton–antiproton collider, but these kinds of experiments are very difficult at such machines.

6. *"Do you envisage any problem in separating, in your budget submissions, the Basic Research User Facilities categories from the General Science and Research program operations?"*

Answer: There is always some ambiguity in assigning items to one category or the other. At the 10–15% uncertainty level I see no difficulty dividing the budget in the manner indicated, but I do hope that if this becomes standard practice in the future the laboratories will be allowed some flexibility in shifting funds from one category to another to account for these uncertainties and to optimize the resultant program.

QUESTIONS FROM THE MINORITY SIDE

1. *"What will be the gap in FY1989 between the level of operation that you can achieve with the proposed DOE allocation, and the optimal level of operation? How much funding would it take to close this gap?"*

Answer: In an optimum program in FY89 we could run the SLC for six weeks extra, bringing the total to 37 weeks, and could run the SPEAR storage ring for five extra weeks, bringing the total to 24. In the BRUF Operating category this would require an increase of $13 million.

2. *"How much additional Research funding would be required to support an optimal level of operations."*

Answer: An increase of $2.5 million.

3. *"On page six of your prepared testimony you note that SLAC's Accelerator Improvement funding is only a little more than one percent of the present valuation of the SLAC machines, and indicates his hope for an increase in Accelerator Improvement (AI) funds in future years. What would be a more reasonable level for AI funds?"*

Answer: An increase in AI funding to a yearly level equivalent to roughly three to five percent of the replacement costs of the technical components of our accelerators would allow all of the U.S. High Energy Physics laboratories to do a much better job of replacing obsolete subsystems with more modern ones and improving the efficiency of operation.

Sincerely,

Burton Richter

Burton Richter

BR:k

PANEL 3: DOE HIGH ENERGY AND NUCLEAR PHYSICS LABORATORIES

Mr. **CHAPMAN**. Our next panel is Dr. Hermann Grunder, Director of Continuous Electron Beam Accelerator Facility, Southeastern Universities Research Association; Dr. N.P. Samios, Director of Brookhaven National Laboratory, shaking his head back there when I asked about the high-temperature superconducting materials.

Dr. **SAMIOS**. That was a National Academy panel mainly of materials scientists that addressed this issue, Chaired by Al Narath of Bell Labs, and they essentially said it's at least ten years away. So, it's been studied rather extensively. It's a great idea which doesn't, unfortunately, pan out.

Mr. **CHAPMAN**. This is going to be one of the debates that I know you know we will hear in the context of the SSC. Please, Dr. Samios, proceed. We are—our goal was to conclude at 12:00; we are obviously going to run over that, but we will make each of your statements a complete part of the record. Summarize if you can and then—we won't diminish in any respect, particularly as applies to the budget numbers here.

STATEMENT OF DR. NICHOLAS P. SAMIOS, DIRECTOR, BROOKHAVEN NATIONAL LABORATORY, UPTON, LONG ISLAND, NY

Dr. **SAMIOS**. So, let me try to be briefer than I intended to be. Brookhaven is a multi-disciplinary lab, so I'll make a few comments on our high energy physics and nuclear physics, and mainly comment about RHIC, the Relativistic Heavy Ion Collider project.

The High Energy Physics Program is going very well. Our user component is roughly 600 people and I say watch out for the little guy because we have many experiments on the floor now that have a sensitivity of one part in 10 to the 11th, looking at 100 TeV mass range, which surprises may come about.

So, our game is to throw a broad net in physics and look for surprises. And that's one possibility. The other example is one that was mentioned earlier, namely the detector in the salt mine in Cleveland; we were a part of that collaboration.

Professor Goldhaber, my predecessor's director, is a major player in that, in which we looked for proton decay, but instead we saw neutrinos from the sun, which was a very exciting result.

I would be remiss if not saying that our running time in contrast to my previous directors who were rather happy with full operations, we would be, too, only running 16 weeks.

Under these budget stringencies it's not an unreasonable decision by DOE, but I would remiss if I didn't tell you that we have a capability of running twice that for a modest sum of money. It's the leverage factor that Leon mentioned.

In the construction area in high energy, the booster project is going along very well, and we're pleased with its inclusion in the 1989 budget, and we expect to complete it on time and on schedule.

In the area of nuclear physics, again, the budget situation in 1989 will allow for the continuing program at BNL, and as previous speakers pointed out, we have started the study of light-ion physics, which has been very successful, both at Brookhaven and at CERN. Experiments are going on and there have even been surprises which confirm our feelings that one can attain large energy densities.

I'd rather concentrate my final remarks on RHIC, Relativistic Heavy Ion Collider. Coming last, it makes my charge more easy.

I think the physics case has been made by many people. It's understood by everyone that this facility will allow you to get to very high energy densities, and get the quark-gluon plasma, that there's a community out there waiting, anxious to do the physics.

Just to really be convinced of that, even the journalists believe it, and I have three copies of the latest *Physics Today,* which has an article starting on Page 17, for three pages.

If journalists are convinced, I think anybody can be convinced. I even guess right; I have three copies for the three Congressman, which you can then read at your leisure.

The physics case is made, there is strong community support. There have been reviews by many national panels, and they reemphasize the complementarity between CEBAF and RHIC, that they are forefront machines, that they explore the quark-gluon plasma, and so again, one isn't going to get sand-bagged by the community.

Concerning technical costs and management issues, there have been lengthy reviews, the last one in May of last year where DOE has validated the project and their comment is "machine is ready for construction."

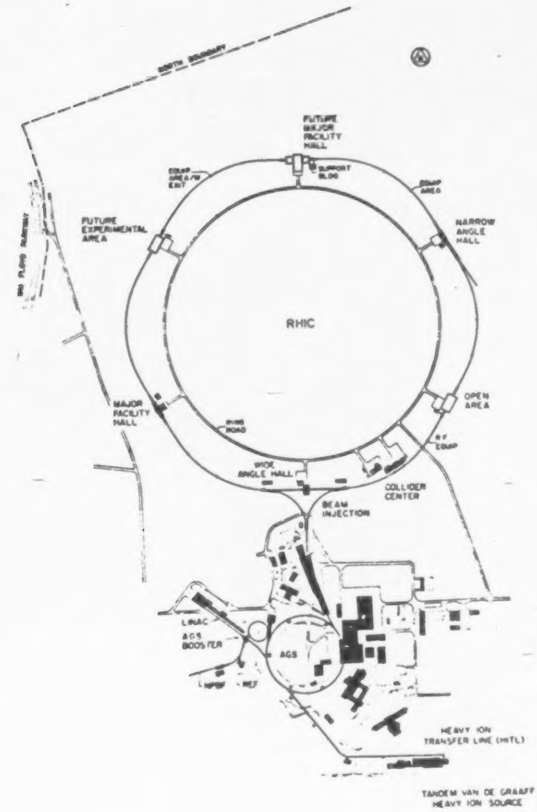
Furthermore, it is a unique facility in the sense that it will have an energy range 100 times greater than any machine in existence now, and ten times larger than any potential machine that's on the horizon, and that would be the upgrade of the CERN facility. So again, it will be a unique, world-class facility.

My final comments have to do about the timeliness of the project. It is not a new concept, it has been going on since 1983. In fact, the first design that Brookhaven proposed occurred in 1984.

Therefore, that means that this project has been refined many times, its costs have been examined rather carefully, its technical details, and it's really ready to go.

There is a very competent team ready to build it and, the real comment is this is a grand opportunity for us. We have been the pioneers in this field of relativistic heavy ion physics, we thought of it first, we got off the dime, the experimental program is going very well, and if we delay again, one will then allow other people to catch up; and then, to do it, it's doing it at a time when you have—allowing the competition to catch up.

It is very cost effective in a sense—could I have a transparency just to give you a feeling of where we are right now. The first one of the project, if we could cut the lights.


NORTH BOUNDARY
WM FLOYD PARKWAY
FUTURE MAJOR FACILITY HALL
EQUIP AREA/W EXIT
SUPPORT BLDG
EQUIP AREA
FUTURE EXPERIMENTAL AREA
NARROW ANGLE HALL
RHIC
MAJOR FACILITY HALL
RING ROAD
OPEN AREA
RF EQUIP
WIDE ANGLE HALL
COLLIDER CENTER
BEAM INJECTION
LINAC
AGS BOOSTER
AGS
HEAVY ION TRANSFER LINE (HITL)
TANDEM VAN DE GRAAFF HEAVY ION SOURCE

SITE MAP

Fig. 1

If one had to reproduce this facility any where else, it would cost you twice as much. The infrastructure and the injectors are presently in place. The heavy ion injectors from the tandems, the yellow complex, has been energized; it is in place; it injects into the AGS which the green complex, and the experimental programs are now underway.

The RHIC proposal is on the north part of the sight in blue. The tunnel is in place. The refrigerating plant is in place. What remains to be put in are the magnets.

The magnets are the major part of the project, they're half the cost of the project. And so, we pay particular attention with our R&D funds from DOE, which started with $3 million in 1987, $6 million in 1988, and $6½ million in 1989, and to just apprise you of the status of that, could I have the next slide.

We have built four full-scale, full-size magnets and I would say they performed above spec. On field quality, they are machine-quality magnets. What is displayed here for each of the magnets is the magnetic field, the quench history of the magnet. In other words, you raise the superconducting magnets so they become normal, then they quench, then you do it again and what you like to see is roughly a flat plateau.

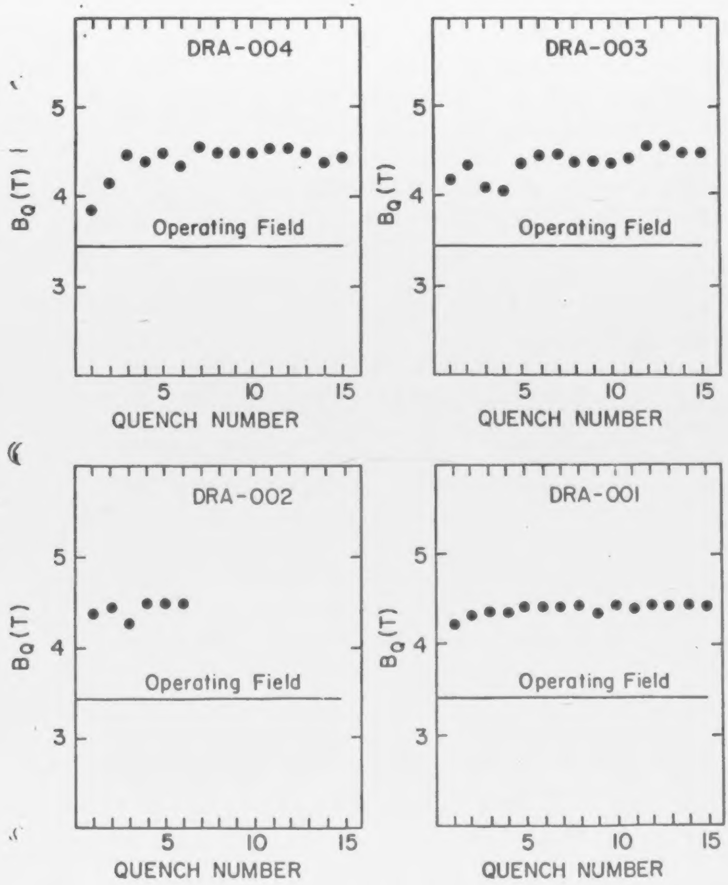

DRA-004
DRA-003
DRA-002
DRA-001
$B_Q(T)$
Operating Field
3
4
5
QUENCH NUMBER
5
10
15

Fig. 2

The solid line for each of these magnets which is 3½ tesla, is the operating field. And what you see for each of these commercially produced magnets, the first quench, even without doing anything, is above the operating field.

And furthermore, that ultimately reaches a field that is 20 to 30 percent above operations. So, we feel very comfortable that the magnet, the key element which are the magnets, are well at hand and right now we're building even further magnets which will be of sufficient quality to go into the tunnel themselves.

Finally, costs. Could I have the last transparency. Costs are always cheaper, as I said last time, in 1910 dollars, but unfortunately we're in 1988, and what I've noted here on the top line is a projected cost for a five year construction project for the RHIC machine, totaling $205 million.

That includes contingency. In a sense, if you remove contingency that number would be $170 million, so there's a 22-percent fudge factor put in which is necessary. But, if one wanted to low ball it, one would have put the number 170, but this is the real number, 205.

We also, in all projects now in DOE, we do allow for detectors. And we have allowed for $70 million for detectors, and again contingency is in. The detector cost would be 58 if it were not so, leading to a total cost of 275.

My final comment is it's a cost effective, unique facility which has been under design and scrutiny for the last three to four years. We're ready to go, and we're disappointed that the funding is not in the 1989 period budget.

Thank you.

[The prepared statement of Dr. Samios follows:]

Written Testimony of

Nicholas P. Samios, Director

Brookhaven National Laboratory

before the

Subcommittee on Energy Research and Development

of the

House Science, Space and Technology Committee

March 30, 1988

I thank you for the opportunity to once again testify before this Subcommittee on Energy Research and Development. As you know, Brookhaven National Laboratory is one of DOE's multidisciplinary national laboratories and thus has activities in many fields of science and technology. This afternoon I will testify on two major areas of our research, namely, high energy and nuclear physics, with particular emphasis on the proposed construction of the Relativistic Heavy Ion Collider (RHIC) at BNL.

The high energy particle physics program at the Alternating Gradient Synchrotron (AGS) at Brookhaven continues to be vigorous and exciting. Our user community keeps increasing and our external Program Advisory Committee must be extremely selective and thus rejects approximately 50% of the proposed experiments--maintaining the high standards of review and acceptance. The experimental program, discussed on previous occasions, involving the search for rare decay modes of K^o mesons (1 part in 10^{10}) is underway. Four experiments are taking data and we are looking forward to their interesting results forthcoming over the next years. The high energy FY'89 operating budget at BNL is projected to be 6% higher than the previous year. This will allow for the continuation of the program at approximately the current level, namely, 16 weeks of slow beam running at the AGS, roughly half of its capability. As a result, we will be able to run the polarized proton program and the neutrino program only every other year. We are pleased by the increasing support of our Center for Accelerator Physics (CAP) where our accelerator physicists and Fellows are exploring novel, forward-looking methods of accelerating particles. In addition, we are gratified by the continued support of the construction of the AGS booster. The FY'89 budget contains $14M for this project which should ensure its completion on schedule with the projected $5M in FY'90. This is a reasonable program considering the pressures on the federal budget and the deficits. However, with regard to the operating budget, I would be remiss if I didn't point out the enormous opportunities afforded by the well known leverage factor for running facilities; in our case, each additional $250K adds one week of AGS running and an increase of $2M would restore the operating program to its level of four years ago.

In the area of nuclear physics the BNL FY'89 operating budget is ~ 6% larger than that of FY'88. This essentially sustains the ongoing program initiated in the previous years. This is mainly centered around the AGS where we have successfully accelerated light ions of mass A = 30 to an energy of 15 GeV/Amu or 450 GeV. There were 7 weeks of running in FY'88 and 8 weeks are planned for FY'89. Many small experiments have been run and completed, with 3 additional major experiments in various stages of data taking. Some of the early results have confirmed our expectations that the energy density of the nuclear system increases as the bombarding energy increases, and furthermore that the AGS energies are the regime for maximum stopping--that is two colliding nuclei completely stopping each other. Extensive data have been taken with oxygen and silicon nuclei impinging on aluminum, copper, gold and lead. There has been a surprise. In these nuclear interactions it has been observed that the ratio of K^+/π^+ mesons is about 25%. This is much larger than the 5% for this ratio observed in pp collisions.

There are many conjectures as to the origin of this effect, however, it is premature to focus on any one--more extensive data is needed. Good progress and great excitement!

I now turn to the final topic of my presentation, RHIC, the Relativistic Heavy Ion Collider. As you know, I have kept this Committee abreast of progress on this project in my previous testimony of 1986 and 1987. In effect the R&D program is going well and according to plan. As noted earlier, the initial heavy ion programs at BNL and CERN with light ions and lower energies are underway. There is a user community of over 400 physicists and growing every day. The interest, theoretical and experimental, in this new field of relativistic heavy ion physics as evidenced by publications is growing by leaps and bounds. The early experimental data have borne out our expectations. We now have even greater confidence in our prediction of the formation of the quark-gluon plasma at RHIC energies. The DOE R&D funding for this project covering FY'87 ($3m), '88 ($6M) and now '89 ($6.5M), although less than optimum, has allowed for substantial progress, especially in the magnet area. The surprise and I must say disappointment is that there are no construction funds requested for RHIC in the Presidential budget for FY'89.

As has been noted many times, the study of relativistic heavy ions is an exciting new field of nuclear physics. It has become so because of advances both in our understanding of the basic constituents of matter, quarks and gluons, and also due to our increased technical abilities to build cost effective accelerators to explore this new domain. We now strongly believe that matter is made of quarks and gluons, and furthermore, that these fundamental particles cannot be isolated in the laboratory but only exist inside a nucleus or nucleon, i.e., they never can become free. However, we want to study their interactions, the dynamics and thermodynamics of quarks and gluons. To accomplish this one needs many quarks and gluons, therefore heavy nuclei A = 200, and further, if one wants them to freely interact, then one requires large nuclear densities, therefore high collision energies. The energy question has been studied in some detail and the consensus is that 200 GeV/Amu, in the center of mass, the RHIC design energy, is a reasonable and conservative value that should produce the required energy densities for quark gluon plasma formation. This is two orders of magnitude (100x) larger than attainable at any present machine and 10 x larger than any presently planned accelerator. The interest and participation in the physics is evidenced by; the large and active user programs at BNL and CERN where major experiments are producing interesting data at lower energies with light ions; the increase in the number of conferences and workshops devoted to this subject--large international conferences now held yearly instead of every other year--and, of course, much enhanced number of publications.

The conception of the RHIC project goes back many years with the first serious consideration evidenced by a design developed in 1984. Since then this has been refined several times, emerging with the present cost effective, validated, RHIC design with a five year construction schedule and a FY'89 start. This plan has been supported with an R&D effort beginning in FY'85 and FY'86 with laboratory funds and FY'87 thru FY'89 with DOE R&D funds, culminating in a conclusion by a DOE technical, cost and management review of May 1987 stating "RHIC is ready for construction".

The nuclear and scientific community have consistently supported RHIC from 1983 to the present. This has involved DOE/NSF/NSAC long range planning committees, stating

> "... the United States should proceed with the planning for the construction of this Relativistic Heavy Ion Collider facility expeditiously; and we see it at the highest priority new scientific opportunity within the purview of our science."

Such a facility received similarly strong endorsement in the National Research Council report Physics Through the 1990's (Brinkman Report, January 1986):

> "Two nuclear physics accelerators, of complementary nature, are recommended ... One is an Electron Accelerator ...; the other is a Relativistic Heavy Ion Collider."

In June 1986, the NSAC Subcommittee on New Facilities and National Laboratories addressed specifically the RHIC proposal.

> "The recent development of the field of Relativistic Heavy Ion Physics has further strengthened the very high scientific merit for this project.... RHIC will provide nuclear science in the United States with a unique world-leading facility with almost unparalleled potential for new discovery."

The proposed RHIC facility will fulfill all of the requirements for this important goal of the U.S. scientific program.

At its most recent meeting, NSAC again reaffirmed its strong support and conviction that RHIC must be built and re-emphasized the importance of a FY'89 start. On a more personal basis, I have had a high level blue ribbon committee chaired by Professor A. Bromley of Yale, advising me on RHIC for the past four years. Its members are drawn from the major U.S. nuclear national labs and universities as well as distinguished representation of the international community. They have also in their most recent (1988) review confirmed that RHIC is a forefront and unique project that should start construction immediately.

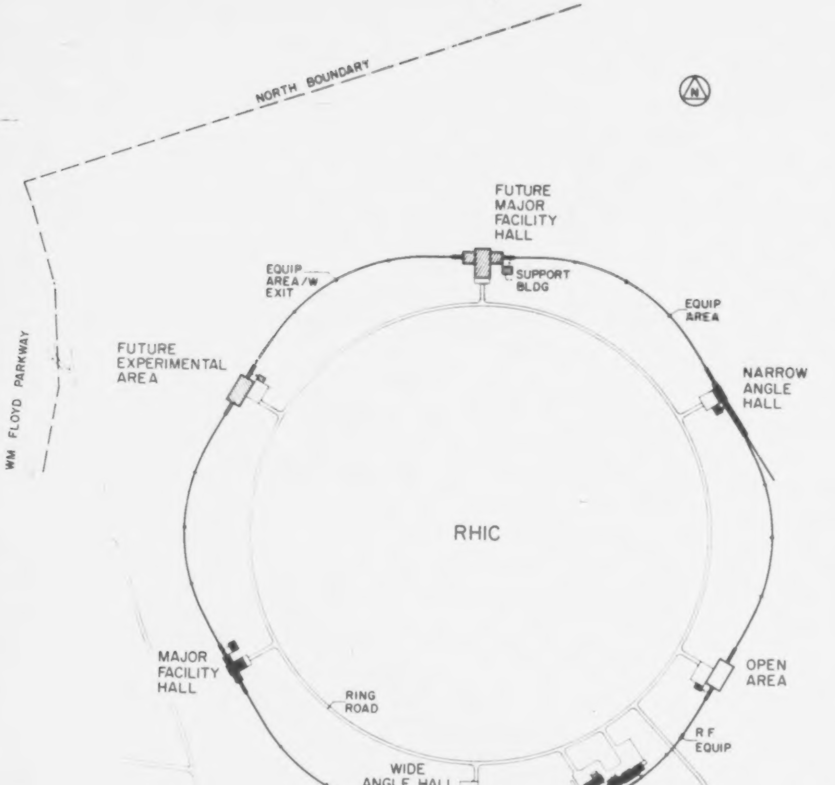
I remind you that the RHIC collider consists of two rings of superconducting magnets capable of accelerating, storing, and bringing into collision two beams each with energies up to 100 GeV/amu for the heaviest ions. The collider will produce center of mass energies which cover the entire energy range from 14 to 200 GeV/amu. The energy range is covered without gaps and with sufficient beam intensity to generate thousands of interactions per second, thus permitting the design of extremely sensitive experiments. The collider will have the flexibility of using the full range of ion species, from protons to gold, which will be available from the Tandem/AGS injector complex. With protons, energies of over 250 GeV in each beam will be possible. The capability for collisions between different species will also be provided; for example, gold versus protons would be possible at 100 GeV/amu in each beam.

The site map is shown in Fig. 1 where the injector (tandem, transfer line, booster), the AGS and RHIC tunnel are displayed. The RHIC ring lattice has 6 arc sections and 6 intersection regions where the beams collide. The superconducting dipole magnets, of which there are 288 in the arcs, are a cold iron design and have a single-layer, cosine-theta coil configuration with 8.0 cm aperture and a yoke length of 9.7 m. The magnets are designed to operate at a field of 3.5 Tesla at a temperature of 4.5 K. These are relatively low-field magnets which utilize technology which is well-tested and understood. Most of the physical plant for the collider exists, including an operating helium refrigeration system, and only a modest expenditure is required to complete all the remaining conventional facilities.

It is not appropriate in this testimony to go into any detail on the R&D results, the review committees cited above have done that. However, I should like to remark on the magnet program since it is the single most expensive and difficult part of the project. Since I last spoke to you, four full length, full aperture superconducting dipole magnets have been tested. They all performed according to specification for field quality and 20-30% above specification for magnetic field value, attaining 4.5 Tesla where 3.5 Tesla is required. Their training history is shown in Fig. 2. We are now in the process of constructing final prototype dipole and quadrupole magnets, that is they would be of sufficient quality to be put into the tunnel for the RHIC machine.

I conclude by discussing costs, these are noted in Fig. 3. These costs have been verified and deemed reasonable and include costs for experimental detectors as well as contingency. The machine cost is $205M in FY'88 dollars and is spread over a five-year period beginning with $15M in FY'89. We have great confidence in this number due to the numerous in depth reviews and refinements that have taken place since 1984, and furthermore since approximately half of the project is already in place--the injectors, tunnel, refrigeration system, etc. Since detector costs are now included in the construction project, we have had several workshops each consisting of over 100 physicists to design prototype experiments and estimate their cost in detail. We are refining this process with further interactions with experimenters on this question this month, and at a two-week session this summer. The detector costs are $70M including contingency in FY'88 dollars. This will allow for equipping four experimental areas to explore the physics at RHIC.

I hope this discussion has brought you up to date on this project. We believe it is a unique, cost effective project, that will be at the cutting edge of nuclear physics. It is ready for construction and we are eager and anxious to build and operate this facility and to derive the expected exciting physics with RHIC.


NORTH BOUNDARY
N
WM FLOYD PARKWAY
FUTURE MAJOR FACILITY HALL
EQUIP AREA/W EXIT
SUPPORT BLDG
EQUIP AREA
FUTURE EXPERIMENTAL AREA
NARROW ANGLE HALL
RHIC
MAJOR FACILITY HALL
OPEN AREA
RING ROAD
RF EQUIP
WIDE ANGLE HALL
COLLIDER CENTER
BEAM INJECTION
LINAC
AGS BOOSTER
AGS
NPBF
REF
HEAVY ION TRANSFER LINE (HITL)
TANDEM VAN DE GRAAFF HEAVY ION SOURCE

SITE MAP

Fig. 1

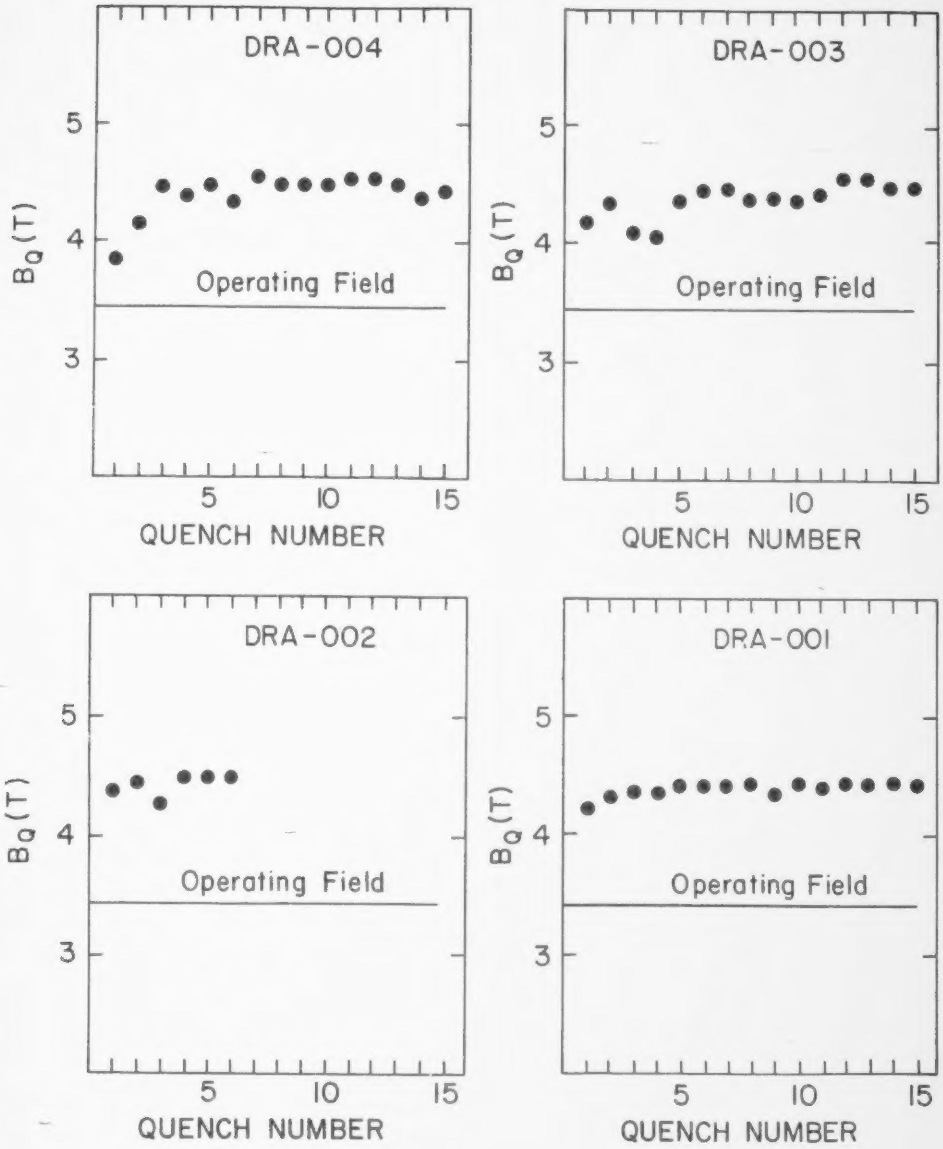

DRA-004
DRA-003
DRA-002
DRA-001
$B_q(T)$
5
4
3
Operating Field
5
10
15
QUENCH NUMBER

Fig. 2

TOTAL PROJECT FUNDING
BY FISCAL YEARS
88 $ (1000,000)

	89	90	91	92	93	TOTAL
RHIC (Machine Construction)	14	42	61	56	32	205
Detectors		1	12	29	28	70
	14	43	73	85	60	275
At Year $ Program (Machine & Detectors)	15	48	87	107	81	338

Fig. 3

CURRICULUM VITAE

N. P. Samios - Brookhaven National Laboratory, Director.

Born - March 15, 1932.

Education

1949--Stuyvesant High School.
1953--A.B. Columbia College, Physics.
1957--Ph.D. Columbia University, Physics.

Employment

Instructor, Department of Physics, Columbia University, 1956-1959.
Adjunct Professor, Department of Physics, Columbia University, 1970-Present.
Adjunct Professor, Department of Physics, Stevens Institute of Technology, 1969-1975.
Assistant Physicist, Department of Physics, Brookhaven National Laboratory, 1959-1962.
Associate Physicist, Department of Physics, Brookhaven National Laboratory, 1962-1964.
Physicist, Department of Physics, Brookhaven National Laboratory, 1964-1968.
Group Leader, Nuclear Interactions Group (Changed to "New Group"), Department of Physics, Brookhaven National Laboratory, 1965-1975.
Senior Physicist, Department of Physics, Brookhaven National Laboratory, 1968-Present.
Chairman, Department of Physics, Brookhaven National Laboratory, 1975-1981.
Deputy Director, High Energy and Nuclear Physics, Brookhaven National Laboratory, February 1981-January 1982.
Acting Director, Brookhaven National Laboratory, January 1982-May 1982.
Director, Brookhaven National Laboratory, May 1982-Present.

Honors and Awards

E. O. Lawrence Memorial Award, 1980.
New York Academy of Sciences Award in Physical and Mathematical Sciences, 1980.
National Academy of Arts & Sciences, Fellow.
National Academy of Sciences, Member.

Professional Societies

Phi Beta Kappa, Member.
American Physical Society, Fellow.
New York Academy of Sciences, Member.
Sigma Xi, Member.

Mr. **Chapman**. Dr. Samios, thank you for your testimony. Dr. Grunder?

STATEMENT OF DR. HERMANN A. GRUNDER, DIRECTOR, CONTINUOUS ELECTRON BEAM FACILITY, NEWPORT NEWS, VA

Dr. **Grunder**. Mr. Chairman, Members of the Committee, Ladies and Gentlemen. Your Committee authorized CEBAF for construction in fiscal year 1987, based on the DOE request as the highest priority new facility for nuclear physics.

Construction, indeed, started on February 13, 1987, shortly before I appeared here the last time.

Progress since then, thanks to the support of your Committee and the Congress, the Department of Energy and the very dedicated CEBAF staff, is substantial.

It has taken place on several fronts. The total staff has doubled to 235 people. Particularly noteworthy is Dr. John Domingo, a renowned experimentalist, who joined us to head the Physics Division. Dr. Domingo is a Nebraskan who provided experimental leadership for the accelerator at the Swiss Institute of Nuclear Research, an institution about the same size as CEBAF.

Domingo's expertise complements that of Scientific Director, Professor Walecka, a noted theorist from Stanford University.

Furthermore, the site has been cleared and two major contracts and many smaller ones have been awarded. An important major contract, the Central Helium Liquefier, has been ordered for $8.5 million, very close to our estimate.

CEBAF's liquefier is to be by far the largest ultracold-helium refrigerator ever built. It is the fourth-largest helium refrigerator in the world.

The contract for the main office building, to be called CEBAF Center, has been awarded for $5.5 million, the cost we estimated. Construction on this complex starts next month.

The construction bid packages for the accelerator tunnel are being finalized and we will start construction this summer.

Our prototyping program is making excellent progress, albeit, a little slower than I would like. We had some delays acquiring and refurbishing the Testlab building we inherited from NASA. This building houses all of our R&D activities.

Industry has continued to produce excellent prototypes of our superconducting radio frequency cavities, the heart of our accelerator. These cavities were developed by a Cornell University team headed by Ron Sundelin, and sponsored by the National Science Foundation.

Dr. Sundelin and a fair fraction of his team are now CEBAF employees and continue their excellent work.

We have completed our first cryo-unit, the building block of our accelerator system. Each cryo-unit houses two superconducting cavities, keeping their temperature near absolute zero. We will now get ready to order the cavities and cryo-unit parts from industry.

These will be assembled and tested in our Testlab before being installed in the accelerator.

We have assembled and tested the electron gun for the injector of CEBAF. It produces the required beam quality, and we are working on developing the rest of the injector.

Last but not least, we have made real strides in developing our control system. For our cryo-unit tests we are now using the actual hardware and software that will be used to operate the completed accelerator once it is finished.

For me, the user community of enthusiastic physicists provides both incentive and reward. These future users are energetically preparing to use CEBAF to do truly exciting physics experiments.

We currently count 667 physicists in our user community; 192 of them, from 50 institutions, have submitted letters of intent to propose a specific experiment. And this is five years before beam will be delivered.

In the last two months, six meetings involving 20 to 60 physicists discussed and evaluated specific experiments to exploit the enormous potential of CEBAF.

Based on this response from the users, plans are shaping up for strong, multifaceted research programs in each of the three experimental halls. In this regard, the availability of three separately adjustable beams means that three truly independent research efforts can be pursued. Many universities, among them Illinois, Caltech, MIT, Maryland, Virginia, William & Mary, South Carolina, the Argonne National Laboratory, and I could go on and on, are taking real initiative to participate in equipment development.

Two critical milestones are approaching fast. We must freeze the dimensions of the experimental halls by May, and prepare the equipment plan by fall of 1988. Construction of the experimental halls and fabrication of the experimental equipment, should start in FY 1989, wouldn't it be for the containment of the construction costs.

Allow me now to talk a little bit about funding. The $16.2 million of construction funds appropriated by Congress for FY 1987 have been obligated. We are placing contracts to commit the $33.5 million appropriated for FY 1988, and regret that this Committee's recommendation for increased funding did not materialize a year ago.

The President's budget for FY 1989 requests $44.5 million, down $20 million from the projection of a year ago. This reduction extends the construction phase by six months, and causes the total estimated construction cost to increase to $265 million.

Project completion slips to late FY 1993. Realizing the pressures on the Federal budget, I am committed to managing each Congressional authorization to achieve the optimum benefit.

However, the construction delay puts additional strain on our operating budget. This budget is already stretched very thin to support the myriad activities required to establish a laboratory infrastructure and pursue critical R&D. Our staff growth was planned to match the projected construction profile, so we find ourselves in a bit of an awkward position when funding doesn't keep pace.

Let me close with two general comments. First, in General Sciences, a real renaissance is taking place. You heard from the high energy physics laboratory the excitement at Fermilab and at

SLAC. This is based on the long range plans of these fields and supported by DOE and the Congress,

For me, a particularly telling sign is that remarkably bright and talented young people are participating in these activities in a growing number.

In this context, it is unfortunate that DOE has delayed the Relativistic Heavy Ion Collider, which will complement CEBAF scientifically in important ways, as you heard from Dr. Samios.

CEBAF and RHIC, together with the SSC and the synchrotron light sources, will provide unparalleled opportunities for university and laboratory scientists in the United States to explore frontiers of knowledge well into the 21st Century.

Today's activity reminds me very much of the enthusiasm in the late 1950's and early 1960's when the research opportunities in the United States were irresistible to many of us Europeans.

Finally, I trust that the new category of basic research users facilities signals a commitment to use these new facilities effectively, and thereby capitalize fully on the unprecedented research opportunities they afford.

It was a great pleasure to appear before you and I hope you all come down to visit CEBAF real soon.

[The prepared statement of Dr. Grunder follows:]

Written Testimony of Dr. Hermann A. Grunder, Director,
Continuous Electron Beam Accelerator Facility
before the
Committee on Science, Space, and Technology
Subcommittee on Energy Research and Development
March 30, 1988

I am pleased to have the opportunity to report to you on the progress and most recent accomplishments at the Continuous Electron Beam Accelerator Facility–CEBAF–a new research tool designed to advance the frontiers of knowledge in nuclear physics. Since I reported to you last year, just after the bulldozers arrived to start clearing the site, we have made real progress on several fronts: site preparation, component development, and physics planning. We have also placed our first large contracts. Our community of prospective physics users has increased by some 200 physicists to 667, many of whom are now heavily involved in designing experimental equipment and forming collaborations. In the past five weeks alone, six focused meetings have each brought 20 to 80 physicists to CEBAF for specific planning and design work. CEBAF's progress and success to date are due in no small measure to the efforts of many players: the U.S. Congress, DOE, industry, the nuclear physics community, the Southeastern Universities Research Association (SURA), and the CEBAF staff.

CEBAF'S ROLE AS A BASIC RESEARCH USER FACILITY

The facility under construction in Newport News, Virginia, is but one of several major research tools needed to advance this country's basic research capability. Many fields -- from biology to medicine, from physics and chemistry to materials -- are in a stimulating and challenging phase, where today's studies point to new frontiers, requiring sophisticated new experimental tools to take the next major steps in understanding. Exciting initiatives, such as the new synchrotron light sources, the Superconducting Super Collider (SSC), the Relativistic Heavy Ion Collider (RHIC), and CEBAF have been proposed or launched to access today's frontiers. These facilities will provide unprecedented research opportunities for university faculty, students, and laboratory and industry scientists across the country. Much credit goes to the leadership in the Department of Energy for encouraging such an impressive array of state-of-the-art scientific ventures. Great appreciation is due to Congress for supporting these initiatives in a difficult budget climate.

The primary purpose of these initiatives is to advance our understanding of the world and build the base of scientific knowledge to serve future generations. This activity stimulates and inspires the bright young people of this country and intrigues and excites American citizens at large. At the same time, construction and operation of these facilities spur technological innovation by challenging U.S. industry to develop components and capabilities meeting the exacting technical requirements of the new machines.

To explore the frontiers of nuclear physics through the 1990s and into the 21st century, thereby gaining a deeper, more detailed understanding of the structure and workings of the atom's nucleus, requires coordinated study using sophisticated accelerators providing three complementary experimental probes: electrons, hadrons, and heavy ions. Such a coordinated program is developed and advocated in the Nuclear Physics Long Range Plan. Los Alamos National Laboratory is the center providing hadronic probes in this country. The Bevalac at Lawrence Berkeley Laboratory and RHIC, currently approaching readiness for construction at Brookhaven National Laboratory, use heavy ions to study bulk nuclear matter under conditions of high temperature and pressure to explore possible exotic states and phases. CEBAF's role is to use electron probes to study the atom's nucleus in terms of the quark constituents of each proton and neutron, thereby significantly extending research pioneered at MIT's Bates accelerator. I am very pleased that the DOE is keeping Bates active as a frontier research facility.

To meet this challenge, CEBAF has a specialized combination of features duplicated by no other facility in the world: CEBAF will deliver a 4 billion electron volt, continuous and intense beam of electrons. It is the combination of energy and intensity, along with the continuous character of CEBAF's beam, that makes CEBAF both unique in the world and specially suited to advance our understanding of the atomic nucleus in detail.

CEBAF PROGRESS AND PLANS

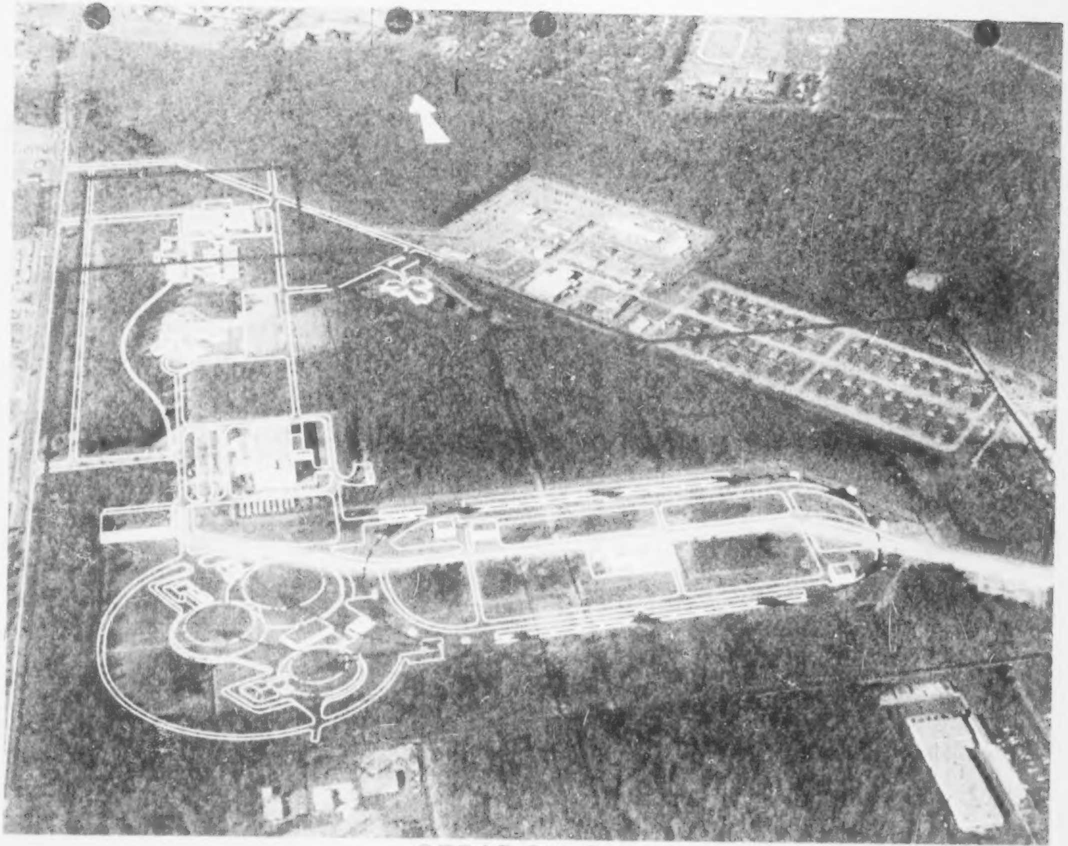
Construction on CEBAF started February 13th, 1987, coincident with the first meeting of the Program Advisory Committee (PAC). In the past year the site has been cleared (Figure 1), we have hired an Associate Director for Research, and the CEBAF staff has doubled to 235. With this growth, we have had to augment the office building provided to us by the Commonwealth of Virginia with numerous trailers, affording functional but somewhat primitive offices. CEBAF looks like a real construction project, replete with mud, gravel, wooden walkways, and limited parking.

Noteworthy progress has been made in civil construction:

- o Clearing and preparation of the site are complete.
- o Construction starts this April on CEBAF Center, our office building scheduled to provide offices, auditorium, and cafeteria by late 1989. The contract cost matches our estimate.
- o The accelerator enclosure design is nearly ready to issue to bidders. Tunnel construction will start in the summer.

Component development is proceeding well:

- o Industry has fabricated ten prototype superconducting RF cavities of the Cornell design. All tested ones significantly exceed specifications. We plan to seek production bids this summer.



CEBAF Site Plan

- We have installed interim **test and assembly capability** in the Testlab, the large NASA cyclotron building inherited by the project. Permanent test and assembly facilities are underway.
- The painstaking development and assembly of the **first prototype cryostat** containing one pair of cavities culminated in a month-long test started in January. This exhaustive test of the cavities and cryostat together demonstrated the soundness of the overall design, revealed minor modifications needed to streamline production and assembly, and verified the importance of absolute cleanliness in handling the cavities to prevent performance degradation.
- Our **electron source** has been in testing since fall 1987, and it meets specifications. We are working on developing the remainder of the injector.

Industrial participation and commitment remain strong, and the engineering expertise of industry continues to contribute to detailed design solutions. We estimate that 80% of the construction cost will be spent on subcontracts with industry. Industry is rising to the challenge of achieving our performance specifications, for an acceptable cost.

- Through FY 1987 we have collaborated with over 200 companies in numerous technical areas.
- The contract for the **Central Helium Liquifier (CHL)** at a price of $8.5 million was only $300 thousand (4%) above the estimate. CEBAF's CHL is to be the world's largest refrigerator delivering liquid helium at 2 Kelvin (-456° Fahrenheit).

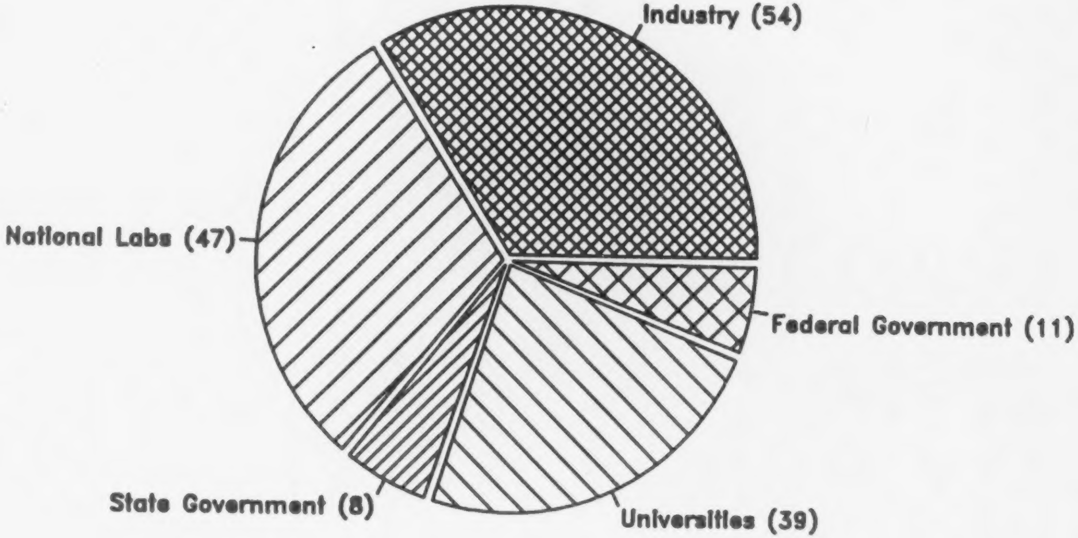
- We have acquired one-third of the accelerator control computers and developed control software being used already in the cryostat testing program and in the development of scenarios for accelerator commissioning and operations.

Perhaps my biggest surprise as Director has been the relative ease of attracting truly excellent staff of all ages and diverse backgrounds (Figures 2 and 3). These individuals have brought their considerable talents, skills, and intelligence to bear on CEBAF's challenges. Creating the environment in which people can do their best work is my most important job. Only in such an environment will the accelerator laboratory we build and operate become a center of excellence, where the best physicists will be attracted to perform truly first-class nuclear physics research.

EXPERIMENTAL PROGRAM AND EQUIPMENT

John Domingo's arrival to assume the helm of the Physics Division completes CEBAF's management team. He and the laboratory's Scientific Director, Professor John Dirk Walecka, a renowned theorist, are directing the planning, development, and execution of the experimental areas and their equipment to serve the experimental program being shaped with considerable involvement of the user community. A native Nebraskan, Dr. Domingo comes to us via Switzerland, where he served as the Experimental Research Director at Switzerland's national nuclear physics laboratory near Zurich.

ORIGINS OF PROFESSIONAL STAFF CEBAF



159 Professional Staff
235 Total Staff
March 1988

Figure 2

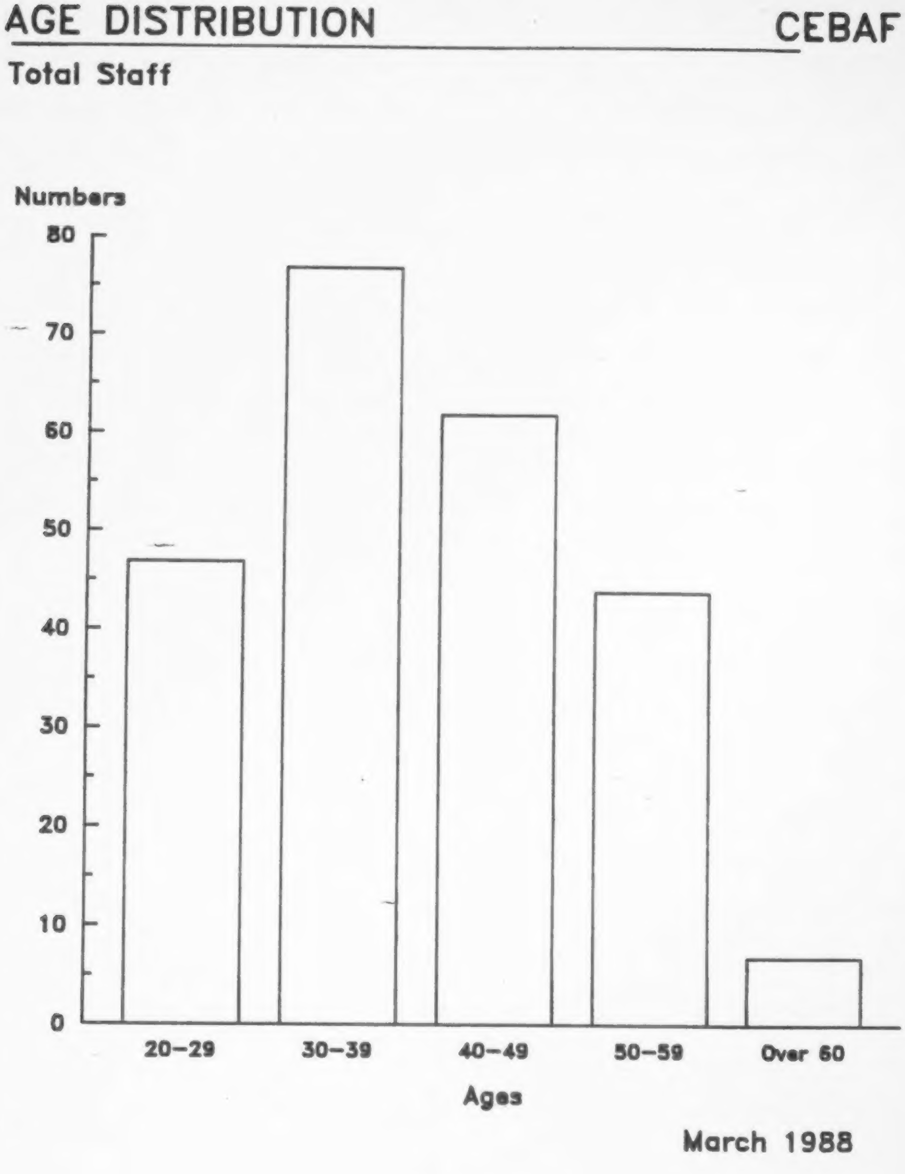

AGE DISTRIBUTION
CEBAF
Total Staff
Numbers
80
70
60
50
40
30
20
10
0
20-29
30-39
40-49
50-59
Over 60
Ages
March 1988

Figure 3

A major focus in FY 1988 is to finalize the plans for experimental equipment and experimental halls. Last fall, 61 Letters of Intent were received from 192 physicists at 50 institutions (Figure 4). These letters describe specific experiments their signers intend to propose to conduct at CEBAF. They provide important information to be factored into the design of the experimental equipment.

Serious, regular collaboration meetings have begun, as the user community plans for CEBAF's experimental program. Already nuclear physics groups at the University of Illinois, Caltech, University of Maryland, University of Virginia, and University of South Carolina are taking real initiative on their own to participate in equipment development. Other university and laboratory researchers are significantly involved. Plans are shaping up for strong, multifaceted experimental programs in each of the three experimental halls. In this regard, the availability of three separately adjustable continuous beams means that the three halls can support truly complementary and independent research efforts.

Our in-house physicists are taking naturally to their most important roles: supporting the users and carrying the burden of implementing the needed experimental facilities. Activity is high, because two critical milestones are approaching fast. We must freeze the dimensions of the experimental halls by May, and prepare the equipment plan for review by our Program Advisory Committee and by the Department of Energy in the fall. Construction of the experimental halls and fabrication of the experimental equipment should start in FY 1989 for us to be ready to take data when the beam comes on.

Universities and Laboratories submitting Letters of Intent for Research at CEBAF (October 1987)

1. Arizona State University
2. Argonne National Laboratory
3. Brookhaven National Laboratory
4. Boston University
5. CEBAF
6. California State Univ/LA
7. Carnegie-Mellon University
8. Caltech
9. CEN-Saclay
10. Christopher Newport College
11. Catholic University
12. CUNY
13. Florida State University
14. Gettysburg College
15. Georgetown University
16. George Washington University
17. Harvard University
18. Kent State University
19. Lawrence Livermore National Lab.
20. LAMPF
21. MIT
22. National Bureau of Standards
23. NIKHEF
24. North Carolina State University
25. Northwestern University
26. Rutgers
27. Rice University
28. RPI
29. Stanford University
30. Syracuse University
31. Tel-Aviv University
32. Temple University
33. University of Alberta
34. University of Houston
35. University of Illinois
36. University of Maryland
37. University of Massachusetts
38. University of Mississippi
39. University of New Hampshire
40. University of Pittsburgh
41. University of Regina
42. University of Richmond
43. University of Saskatchewan
44. University of South Carolina
45. University of Virginia
46. University of Washington
47. Virginia Tech
48. Western Michigan University
49. William & Mary College
50. Yale University

misc1988:pas

Figure 4

CEBAF COSTS

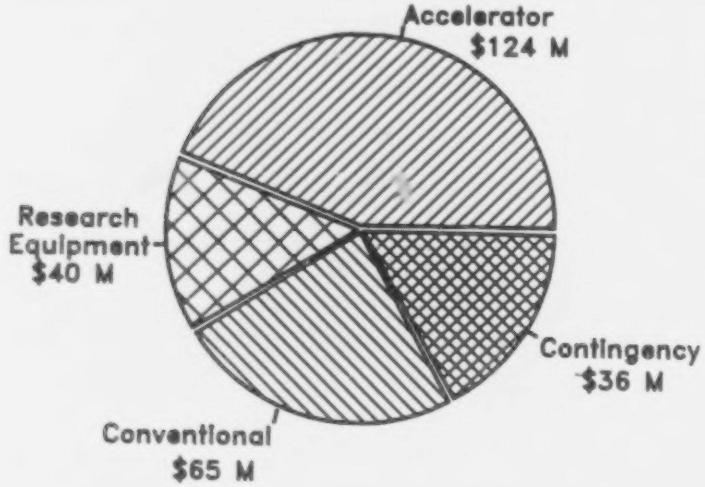
The $16.2 million of construction funds appropriated by Congress for FY 1987 have been obligated. We are placing contracts to commit the $33.5 million appropriated for FY 1988, and regret that this Committee's recommendation for additional funds did not materialize. The President's Budget for FY 1989 requests $44.5 million, down $20 million from the projection of a year ago. This reduction extends the construction phase by six months, which causes the total estimated construction cost to increase $10 million to $265 million (Figure 5). Project completion slips to mid FY 1993.

With the requested FY 1989 appropriation, we will continue tunnel construction, procure key hardware components (cavities, cryostats, and klystrons) -- although more slowly than originally planned -- and we will fund the second phase of the Central Helium Liquifier, already on contract. Procurement of experimental equipment components must be deferred to FY 1990, I hope without losing too much momentum and enthusiasm in the user community, especially among groups involved in our collaborations. The delay is regrettable, but changes to funding levels are a fiscal fact of life. I will continue to respond flexibly to manage each Congressional authorization to achieve the optimum benefit to the project, laboratory, physics community, and nation. However, it is very important that we receive the full request in FY 1989, which represents the minimum level to support meaningful progress.

CONSTRUCTION COST CEBAF

President's Budget FY 1989

$265 M over 6 1/2 Years



PROJECTED BUDGET PROFILE

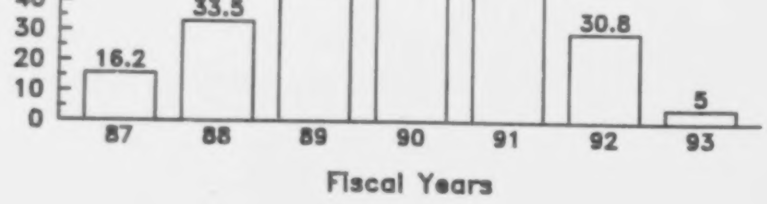


Figure 5

In addition to its annual construction appropriation, CEBAF receives operating funds. These funds are under serious pressure right now. They provide marginal resources for today's activities (e.g. research, development, user liaison, and laboratory operations) that are outside the scope of the construction project, yet essential for its successful accomplishment.

As a final note, I interpret the advent of a separate budget line to support DOE's Basic Research User Facilities (BRUF) as a commitment to fund and utilize these unique facilities properly. Although in principle I oppose separating funding for the physics from funding for the facilities needed to do the physics, I am optimistic that effective coordination between physics and facility operations can be achieved, since administration of both accounts is assigned to the same DOE program office.

SURA UPDATE

CEBAF's progress in the past year has been paralleled by the maturation of the Southeastern Universities Research Association (SURA). Three universities have been admitted as new members: Vanderbilt University (Tennessee), Mississippi State University, and Christopher Newport College (Associate Member, Virginia), bringing the total to 38 (Figure 6). SURA has launched SURANet (a National Science Foundation funded, high-speed regional computer network) and has nearly completed negotiations for the Management and Operating contract for CEBAF.

SURA MEMBERSHIP

CEBAF

ALABAMA

Auburn University
University of Alabama at Birmingham
The University of Alabama

DELAWARE

University of Delaware

DISTRICT OF COLUMBIA

American University
Catholic University
Georgetown University
George Washington University

FLORIDA

Florida State University
Florida Institute of Technology
Florida International University
University of Florida

GEORGIA

Georgia Institute of Technology
University of Georgia

KENTUCKY

University of Kentucky

LOUISIANA

Louisiana State University

MARYLAND

University of Maryland College Park

MISSISSIPPI

Mississippi State University

NORTH CAROLINA

Duke University
North Carolina State University
University of North Carolina

SOUTH CAROLINA

Clemson University
University of South Carolina

TENNESSEE

University of Tennessee
Vanderbilt University

VIRGINIA

College of William and Mary
Christopher Newport College
George Mason University
Hampton University
James Madison University
Norfolk State University
Old Dominion University
University of Richmond
University of Virginia
Virginia Commonwealth University
Virginia Polytechnic Institute & State University
Virginia State University

WEST VIRGINIA

West Virginia University

Figure 6

Capable leaders continue to fill critical roles in the organization. A new President, Dr. William A. Wallenmeyer, formerly head of the DOE High Energy Physics program, has taken over the helm. Chancellor Joe B. Wyatt of Vanderbilt University is the Chairman of the Council of Presidents. Provost George W. Wheeler of the University of Tennessee continues as Chairman of the Board of Trustees. It is timely to acknowledge the contributions and service of two of SURA's early leaders, founding President Harry D. Holmgren (University of Maryland), and Christopher Fordham (University of North Carolina), our tireless past Chairman of the Council of Presidents.

SURA participation in CEBAF's scientific program is strong. To date, 21 of the 30 pledged faculty positions have been filled in nuclear physics. The remaining nine faculty positions have been identified, and active searches are underway to fill them. A few additional positions in CEBAF-related engineering, accelerator physics, and superconducting technology have been created and filled at campuses near the CEBAF site. Furthermore, 48 researchers at 12 SURA universities submitted Letters of Intent for participating in CEBAF's experimental program. Additional faculty and graduate students attend collaboration meetings and workshops.

To accommodate our growing number of users and students, the city of Newport News has appropriated $692 thousand to SURA to fund a modest guest house on SURA property adjacent to the CEBAF site. Construction is scheduled over the next year.

CONCLUSION

In summary, CEBAF has made real progress during the past year. We have fully obligated the $16.2 million appropriated for FY 1987, and are on schedule with commitments in FY 1988. The users are really mobilizing to plan and participate in the experimental program and the development of experimental equipment. CEBAF is well on its way to becoming a first-class, world-leading research laboratory to make Congress and the nation proud. Your vision and support are making this possible.

PANEL 3 DISCUSSION

Mr. **Chapman**. Dr. Grunder, I want to thank you for your testimony and ask only one question, and then I'll defer to my colleague from New York. There is a cost factor to delay. Obviously you have just testified that you were able to quantify both the cost and delay factor. How much do you program if there is a reduction in funding? How much more does it cost us if we move the completion date out in the overall project?

Dr. **Grunder**. We have a rule of thumb. First, you obviously have to do it very specifically and specify what you are delaying, but the rule of thumb is that if you have in such a project of this magnitude (where roughly your expenditure rate is around $50 million per year), if you have a year's delay, you have a $10 million—half a year's delay, you have a $10 million increase in construction costs. What is equally important, and roughly of the same order of magnitude, depending where you are in the construction project—it may be larger—you have an increase of the combined operation dollars because obviously the infrastructure of the laboratory is in place. The administrative needs are there. The doors are open and that, of course, particularly in a single purpose laboratory, is a standing cost which you simply add one half more year to it.

Mr. **Chapman**. Thank you, Dr. Grunder. I recognize the gentleman from Long Island.

Mr. **Hochbrueckner**. Thank you, sir—Mr. Chairman. To Dr. Samios, on the total cost I notice from your chart that you indicated that the total projected cost for RHIC is $338 million over a five-year period? Okay. And half of the total infrastructure is already in place in terms of the tunnel and the air conditioning and all that. I am under the impression that there are other contributors—for example, there are detectors that will be provided by other sources and therefore we all have the opportunity to leverage a lot of other money into the project, because of contributions from others, like Europeans, for example.

How much is involved of the total $338 million—or in addition to that which is leveraged by bringing others in?

Dr. **Samios**. Your point is well taken. Presently, for instance, even on the AGS program, several of our detectors having to do with heavy ions are financed—part of them are financed by outside countries, namely Japan and Western Europe.

It is our projection that in the detector area there is roughly $30 million that would come in, in this form. So looking ahead at the project, we are looking at probably $100 million in detectors, of which $70 million would come from the construction project and $30 million would be augmented by the sources such as you have mentioned.

Mr. **Hochbrueckner**. So moving out smartly with this project would therefore bring in external dollars, which would support our research in the United States?

Dr. **Samios**. Absolutely.

Mr. **Hochbrueckner**. What do the continuing delays that the Department has imposed on construction of the project due to the total estimated cost—and what I mean is, can you project what does each year of delay produce in terms of escalated costs to the project?

Dr. SAMIOS. If you look back at the project, it used to be not $338 million but $300 million and before that, less than that, so each year's delay costs you 5 to 10 percent, but even more important than that is keeping the highly qualified team together, as I mentioned in my testimony, who have been at it since 1984 and to keep highly qualified people on board, they have to have visions of a project. We have been successful up to now with some few exceptions, some even going to my friend at my left, recently, that we lose some people but we share our good people, but my concern is keeping the project group together of such a high technology.

Mr. HOCHBRUECKNER. Well, it certainly seems like you have engendered the support of your colleagues. Several of your colleagues have spoken highly of RHIC and the need to do it.

Now it is my understanding then that what is needed in Fiscal Year 1989 is $15 million to begin the construction and as far as everyone has told us, all of the physics, all of the homework, everything is in place—we just need to get cracking with that $15 million, is that correct?

Dr. SAMIOS. That's correct.

Mr. HOCHBRUECKNER. One of the questions that a Member of the Committee had was relative to some of the experiments that had been undertaken at CERN. They were inquisitive as to whether some of the work that has been done there is in any way serious competition between their program and what you propose to do at Brookhaven with RHIC.

Could you comment about that?

Dr. SAMIOS. Yes. Right now, both at Brookhaven and at CERN, we are accelerating light ions, that is ions with atomic number around 30. The booster project which I mentioned at Brookhaven will enable us to accelerate heavy ions at lower energies, atomic number about 200. The project that was mentioned by Dr. Henley at CERN, namely the new lead injector, would enable CERN to also accelerate heavy ions at their accelerator, but the center of mass energy at CERN is still a factor of 10 below the projected RHIC energy. So it is not a direct competition. I would consider it more of a competition for people who want to work at the booster.

But my concern is twofold. One, if we move smartly with RHIC, the people if they had a choice between working at CERN or Brookhaven, would work at Brookhaven on RHIC and they would prepare—it takes four years to build a large detector, so we're fighting for the heart, souls, and dollars of the outside community.

My other concern is the longer we have a credibility problem, if we keep delaying RHIC year after year, there will come a time when one can easily add further machines in Europe besides the lead injector to get that factor of 10. We believe that factor of 10 in energy is necessary to get to the quarkgluon plasma. One might see inklings of it at lower energies, but both the Brookhaven program and the CERN program are not dedicated, so I think RHIC is unique in that sense, in both its energy capability and its dedication.

So the short answer—the lead injector is not a direct threat from the physics point of view. It is a direct threat from getting people to work there and therefore not work here and also it is the next step and then they could build on that step and ultimately get to a RHIC collider.

Mr. **Hochbrueckner**. So then, clearly there may be some minor areas where there would be competition and perhaps duplication but your quantum leap in energy level should really put you in a different ballgame. And also you are using gold and they are using lead, right? So I assume——

Dr. **Samios**. We're richer. No—your comments are well taken; it is exactly right.

Mr. **Hochbrueckner**. Thank you, Mr. Chairman. Thank you, Dr. Samios.

Mr. **Chapman**. Gentlemen, thank you very much for your testimony today. We appreciate not only your attendance here but the work you do as well.

[Questions and answers for the record follow:]

RESPONSE

Republican Member Questions for the Record
for the Hearing of March 30, 1988, for

DR. NICHOLAS P. SAMIOS, DIRECTOR
BROOKHAVEN NATIONAL LABORATORY

Question 1: Is the pace of the Relativistic Heavy Ion Collider (RHIC) construction technically limited in any way, and if so, what are the specific problems?

The pace with which we are proceeding with the RHIC project is not limited in any way by technical problems. The R&D program for the project has proceeded on schedule, and we are ready to begin construction in FY 1989. We have outlined a five-year construction plan. This time period is determined in part by the guidance we have received from D.O.E. regarding a realistic funding profile, but is primarily determined by the scale of the project: Once construction begins the pace is determined by the requirements for fabricating, testing and installing a large number of superconducting magnets. A more nearly optimum funding profile (i.e., more money in the early years) could reduce the construction period by six months to a year.

Question 2: Is it your intent to procure the superconducting magnets for RHIC from industry? What is your magnet industrialization plan?

It is Brookhaven's desire to procure the major fraction of the superconducting magnets for RHIC from industry. The construction plan which we have developed calls for Brookhaven to transfer the technology for fabricating these magnets to industry, while maintaining the capability for in-house fabrication of some of the more specialized magnets. We have had manufacturing studies for our dipole magnet design prepared by three different industrial firms (Brown, Boveri Corporation, West Germany; Ansaldo, Italy; General Dynamics, USA), all of whom conclude that the RHIC design is very well suited to industrial manufacture. Since we have not yet received realistic cost estimates from industry, our detailed cost estimates are based on the assumption that magnets are built at BNL. (Such a scenario is possible, but would cause an awkward peak in the manpower at the Laboratory, and would make it difficult to, at the same time, undertake the construction of the large detectors for RHIC. We believe that the costs for industrial production should not differ significantly from our estimates.)

In our magnet R&D program we have kept close contact with industry. During the coming year it is our plan to award contracts for industrial manufacture of R&D magnets to at least three firms, to ensure a qualified pool of contractors prepared to bid on production of RHIC magnets when the project receives construction funds. We have a Task Force preparing all the necessary specifications and drawings so that six preproduction magnets can be made in industry in FY89 using R&D funding.

Question 3: You state in your testimony that since you last spoke to the Subcommittee "four full-length, full-aperture superconducting dipole magnets have been tested.: Were these magnets produced by industry or in-house?

As I stated in my testimony, four full-size superconducting dipole magnets have been built to the RHIC design and successfully tested as part of the on-going RHIC R&D program. Three of these magnets were assembled by the industrial firm Brown, Boveri Corporation in Mannheim, West Germany, using coils of superconducting cable supplied by BNL. Brown, Boveri Corporation is a contractor for the HERA superconducting accelerator now under construction at West Germany's Deutches Elektronen-Synchronon Lab (DESY). This important component of our magnet R&D was carried out under a cooperative agreement between BNL and DESY whereby tooling for the assembly of HERA magnets is being made available for RHIC magnets in return for Brookhaven's help in preparing specifications for the procurement of superconductor for HERA.

Question 4: What, if any, funding or equipment commitments, are DOE or Brookhaven seeking from foreign nations for RHIC?

First, as noted above (Question 3), we have an agreement with West Germany's DESY Laboratory whereby, in exchange for Brookhaven's expertise in superconducting materials and cryogenic systems, tooling for the HERA magnets will be made available for the RHIC project. This tooling would cost about $3M to procure otherwise. This agreement is not contingent on any specific manufacturer for RHIC magnets.

Most important, we are actively seeking support from foreign nations in the area of research detectors and the equipping of experiments for RHIC. Detector costs for the first round of experiments are estimated to be $70M (FY 1988 dollars). We expect this amount to be augmented by an additional $20-$30M from European and Japanese sources. The RHIC project has had very strong support in the European community. Of the 180 physicists who have participated directly in the RHIC detector workshop activity over the past year, about 40 are Europeans. Several working group meetings for the design of RHIC detectors have been held at CERN. The Japanese are also very interested. As Director of Brookhaven Laboratory, I have had numerous discussions with leading Japanese physicists who are anxious to get involved in the RHIC program. To this end, language specifically incorporating heavy ion experiments has been added to the Japanese-American treaty for cooperation in high energy physics.

Subcommittee on Energy Research and Development
Hearing on the Department of Energy (DOE)
FY 1989 Authorization Request for General Science and Research
March 30, 1988
Questions for the Record for Dr. Hermann A. Grunder

1. **What is the basis for your opposition to separating funding for the physics program at CEBAF from the facility funding as is mandated by the Department of Energy's budget submission that includes the Basic Research User Facilities appropriation line item?**

   The major facilities and their operation must serve the physics research program. Therefore, I favor closely coordinated management of the physics research and the facilities. I interpret the Basic Research User Facility appropriation line item as a commitment of the Administration to fund and utilize the large facilities effectively. From this angle, I support the new budget category.

2. **If you were to receive the additional $20 million as requested in last year's estimates for FY 1989 construction funding, how would these funds be used and how would they help to assure that the project would be completed on schedule and without further escalations in the total estimated cost of the project?**

   An additional $20 million would restore CEBAF to the funding profile and schedule projected in the Administration's FY 1988 Budget Request. The additional funds in FY 1989 would be used to maintain the industrial base by allowing us to procure cavities, cryostats, and klystrons on the schedule originally planned. In addition, we would be able to start procuring the long-lead-time components of the experimental detectors being designed now, in close collaboration with the user community. If the $20 million reduction in FY 1989 funding were restored soon, and appropriate planning can occur, then the schedule slip and the escalation of the total estimated cost could be recovered.

3. **What would be an optimal level of construction funding for CEBAF in FY 1989?**

   An optimal level of construction funding for CEBAF in FY 1989 would be $65 million.

4. **Is the pace of CEBAF construction technically limited or funding limited, and if the pace is technically limited, what are the specific problems?**

   The pace of CEBAF construction is funding limited. We are making good technical progress on prototyping and on construction, as I reported in my testimony. With additional construction funds we could speed up the schedule of hardware procurements and civil construction.

5. **How rapidly could CEBAF be brought on line if the project was optimally funded? What funding profile would accomplish this more rapid schedule?**

CEBAF could be brought on line in Spring 1993 if the project were funded optimally. The construction funding profile (in actual year million dollars) to support this schedule follows.

	87	88	89	90	91	92	93	TEC
Construction Funds (BA)	16.2	33.5	65	65	55	20.3	--	255

6. **What, if any, funding or equipment commitments, are DOE or SURA seeking from foreign nations for CEBAF?**

To my knowledge DOE is not seeking explicit foreign contributions to CEBAF. CEBAF is discussing with interested parties in foreign nations the possibilities for foreign groups to build or provide detector components and other instrumentation associated with the experimental program.

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PANEL 4: DOE NUCLEAR PHYSICS LABORATORIES

Mr. CHAPMAN. Our final panel: Dr. Ernest Moniz—somebody tell me if I am not saying this right—Director of the Bates Laboratory at MIT and Dr. Gerald Garvey, Director of Los Alamos—Physics Facility at Los Alamos National Laboratory.

We would like to thank you both for being here and appreciate your attendance and look forward to your testimony. Dr. Moniz, you may proceed, and as with the previous witnesses, your complete statements will be made a part of our Committee report record.

We appreciate your summarizing and really stressing the budget numbers.

STATEMENT OF DR. ERNEST J. MONIZ, PROFESSOR OF PHYSICS AND DIRECTOR, WILLIAM H. BATES LINEAR ACCELERATOR CENTER, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, MIDDLETON, MA

Dr. MONIZ. Thank you, Mr. Chairman. The national program of basic research and nuclear and particle physics has and is developing as a center piece, a set of large user facilities providing complementary probes for the study of matter.

You have heard today about the programs and developments at several of these. Another major component of the nuclear physics program, often less visible but equally vital, is that made up of university based facilities, producing first-class science and first-class young scientists.

I am the Director of the MIT Bates Laboratory, and I appreciate very much the opportunity to describe to the Committee our research and educational program, and our plan developments.

In particular, we are embarking on a major experimental initiative, the South Hall Ring, which will open up a novel program of internal target experiments fully using polarization for the first time with electron beams.

Together with CEBAF, this will lead to a world leading program of basic nuclear physics research with electrons, realizing one part of the program set forth in the 1983 NSAC Long Range Plan for nuclear science and its subsequent updates.

Our initiative will, I hope, also to serve to emphasize more generally for the Committee the crucial importance of very cost effective, yet forefront, initiatives at our universities.

I recall the statement of the White House Science Panel on the health of U.S. colleges and universities, the 1986 Packard-Bromley report, "In this country we are uniquely dependent upon our universities for both research and higher education; perhaps our greatest strength here has been an insistence that the two are inseparable and symbiotic."

An appropriate mix of large user facilities and university based laboratories is not only feasible, but essential, for a robust nuclear physics program in the next decade.

Consequently, it is crucial that budgeting for the field maintain a balance between diverse program elements, a balance which appears to have been struck reasonably in the DOE 1989 budget request.

This balance is particularly important in the current times of fiscal austerity, when the ability of university based research programs to take on and train effectively promising young scientists is resource limited.

Perhaps a brief description of the Bates Laboratory is in order. The MIT Bates laboratory has been functioning since 1974, operated under the joint auspices of the MIT Laboratory for Nuclear Science and the Department of Energy.

MIT has a long and rich tradition, and strong commitment, to the field. Indeed, today, about one quarter of the faculty, and about 45 graduate students, are involved in the program.

It should be stressed, however, that physicists from other institutions do play a major role in Bates experiments and developments. Indeed, physicists from about 50 other institutions are involved and receive well over half of the available beam time.

The MIT/Bates experimental program has supported a vibrant educational program. An NSAC recently referred "to MIT's exceptional role in graduate training for nuclear physics."

About 50 Ph.D.'s have resulted from the program in the last decade, including Oppenheimer Fellows at Los Alamos, researchers in high tech industrial environments, faculty at leading universities.

The South Hall Ring initiative, in leading to novel research possibilities, will sustain the success of the program in attracting and broadly training scientifically aggressive young researchers.

The heart of the Laboratory is a Linac, which produces very high quality, high intensity pulsed electron beams with a maximum energy of one billion volts. The electron beam is then transported to one of two major experimental areas.

Of particular relevance today is the South Hall, which contains two experimental stations and the required instruments for coincidence experiments.

However, continuous rather than pulsed beams, are needed for vigorous pursuit of such experiments. This represents one of the urgently needed capabilities in our field.

Another important capability is that of polarization. Only then can the full power of the electron, as a precision probe of matter, be exploited. A polarized beam has now been developed at Bates, and some exploratory studies are being advanced.

This program is unique. However, a full capability will be at hand only with additional development of useful polarized targets.

So, to repeat, the new capabilities which we need are known. Continuous beams and full utilization of polarization. The South Hall Ring project at the Bates Laboratory, is an experimental initiative which will provide both capabilities throughout the important energy range available to the existing accelerator.

It is very cost effective, $14 million over four years, and indeed, will be funded as part of the on-going nuclear physics base program.

The ring will be an integral part of the South Experimental Hall using the previously mentioned experimental areas in the internal target mode, and in the extracted beam mode.

In the internal target mode, the electrons will circulate thousands of times through a gas target, introduced into the ring. This both permits and requires the use of exceedingly thin targets.

Advances in laser technology, and surface science, now make it feasible to produce gases of polarized nuclei of sufficient thickness for internal target use.

In considering potential developments at Bates, NSAC has stressed that the "combination of internal target capability and polarized beams for addressing important new areas will be unique in the world." Further, the program is totally complementary to that planned for CEBAF.

Indeed, with the South Hall Ring and the major new facility at CEBAF, the American community will have available unmatched electron capabilities built upon novel technologies.

We are enthusiastic about our science, about the technical innovations we are pushing to realize that science, and about the new opportunities awaiting us.

We are confident in the ability drive and future of the young scientists trained in our program. Nevertheless, I would be remiss in not mentioning that our efforts in the symbiotic research and educational enterprises remain hampered by the current level of operating funds.

All facilities, university-based or at National Laboratories, are significantly under-utilized. Not only are the number and quality of experiments diminished, but the time scale for any major initiative is dragged out.

It is important to realize that this particularly disrupts the careers of young scientists, the graduate student eager to complete his apprenticeship with a significant piece of work, the post doctoral researcher trying to structure a career, or the young faculty member working against a tenure clock.

Clearly, we try to minimize the frustration and maximize the chances for these young people who, after all, are our future; but fiscal austerity inevitably extracts its scientific cost both today and, most crucially, in the supply of succeeding generations.

Of course, we recognize the severe budgetary constraints and many competing needs before the Congress. Indeed, we are very appreciative of the support our field has received in this time of scientific opportunity, but persistent budget deficits.

The dedication shown by many in the government, both here in Congress and also in the Administration, towards strengthening the Nation's basic science research and training programs, sustains our optimism in a vigorous future.

Thank you.

[The prepared statement of Dr. Moniz follows:]

Written Testimony of

Ernest J. Moniz

Professor of Physics and Director
William H. Bates Linear Accelerator Center
Massachusetts Institute of Technology

before the

Subcommittee on Energy Research and Development
Science, Space and Technology Committee
United States House of Representatives

on March 30, 1988

The national program of basic research in nuclear and particle physics has and is developing, as its centerpiece, a set of large user facilities providing complementary probes for the study of matter, of the strong forces governing its structure and motions, and of the elementary constituents and their interactions. The construction and operating needs for these very large facilities are recognized by the Basic Research User Facility (BRUF) budget category. Another major component of the nuclear physics program, often less visible but equally vital, is that made up of university-based accelerator facilities, producing first-class science and first-class young scientists. I am the Director of the MIT-Bates electron accelerator laboratory and appreciate very much the opportunity to describe to the Committee our research and educational program and our planned developments. In particular, we are undertaking a major experimental initiative which will open up an innovative program of internal target experiments, fully exploiting polarization observables for the first time in electronuclear physics. Together with CEBAF, this will lead to a world-leading program of basic nuclear physics research with electron beams, realizing much of the electromagnetic part of the program set forth in the 1983 NSAC Long Range Plan for Nuclear Science and its subsequent updates. Our initiative will, I hope, also serve to emphasize more generally for the Committee the crucial importance of very cost-effective yet forefront experimental initiatives at our leading universities. I recall the statement of the White House Science Council Panel on the Health of U.S. Colleges and Universities (the 1986 Packard-Bromley report): "In this country, we are uniquely dependent upon our universities for both basic research and higher education; perhaps our greatest strength here has been an insistence that the two are inseparable and symbiotic." An appropriate mix of forefront large user facilities (such as CEBAF) and university-based laboratories (such as Bates) is not only feasible but essential for a robust nuclear physics program in the next decade. Consequently, it is crucial that budgeting for the field maintain a balance between diverse program elements, a balance which appears to have been struck quite reasonably in the DOE FY1989 Budget Request. This balance is particularly important in the current times of fiscal austerity, when the ability of university-based research programs to take on and effectively train promising young scientists is resource limited.

The Bates ~~Lanor~~atory

A brief description of who and what we are is in order. The MIT-Bates Laboratory has been functioning since 1974, operated under the joint auspices of the MIT Laboratory for Nuclear Science (LNS) and the Department of Energy. It is located north of the main campus, in the town of Middleton; a photograph is shown in Figure 1. MIT has a rich tradition in and strong commitment to nuclear physics; almost one quarter of the faculty and about forty-five graduate students are currently involved. LNS, which administers the DOE contract for all nuclear and particle physics research at MIT, was founded at the end of World War II and, in the intervening years, has led and influenced many important developments in the field. Hundreds of Ph.D.'s have resulted from this research. The strong intellectual ties with the nuclear theory, heavy ion and particle physics groups in LNS and the Department of Physics create a unique environment of enormous value to the nuclear physicists involved in the Bates experimental program.

It should be stressed that physicists from institutions other than MIT play a major role in Bates experiments and developments. Indeed, physicists from about fifty other institutions are involved and receive well over half of the available beam time. Strong collaborations have been central to practically all of our major initiatives, with an especially strong and sustained involvement coming from relatively nearby universities, such as Boston University, Harvard, University of Massachusetts, University of New Hampshire, Rensselaer, Syracuse and Yale, and from other universities traditionally involved in electron physics, such as Illinois and Virginia. A list of user affiliations is attached as Table 1.

The heart of the Laboratory is a 600 foot long, linear accelerator which produces very high quality, high intensity, pulsed electron beams with a maximum energy of 500 million electron volts. A cost-effective innovation at Bates allows doubling the energy to one billion volts by recirculation of the electron beam for a second pass through the accelerator. A photograph of the accelerator system is shown in Figure 2. The electron beam is then transported to one of two major experimental areas, as indicated in the site plan shown in Figure 3. There, the results of the collisions between the electrons and the target nuclei are analyzed by means of large detectors, for example, the magnetic spectrometers shown in Figure 4. The key to advancing our knowledge is understanding how various phenomena, such as the strong overlap of interacting quark clusters or the synchronous motion of many protons and neutrons, affect the energies, directions, multiplicity and identity of the particles or nuclear fragments emerging from the collisions. In the North Experimental Hall resides a spectrometer with unmatched energy resolution; the underlying technique is an MIT-Bates innovation, with important applications in other areas of nuclear physics. The South Experimental Hall contains two beam lines, labelled "B" and "C" in Figure 3. The three spectrometers, shown in Figure 4 on Beam Line B, provide the opportunity for simultaneous detection of several particles emerging from one collision. Such coincidence experiments open up an entirely new research area but require continuous rather than pulsed beams for full exploitation. We shall return to this below.

Electron, proton, meson and heavy ion beams all play an important role in nuclear physics. The distinguishing feature of the "electron microscope" is the precision which it brings to the study of matter. This has been exploited at Bates (and at "sister" facilities in Paris and in Amsterdam) to produce remarkably detailed pictures of atomic nuclei and of the individual nucleon (i.e., neutron and proton) orbits. Structures less than 10^{-13}cm in extent are resolved. Not only the particles in their quantum orbits but even the "tidal" effects produced by their motion through nuclear matter are clearly seen. Such observations have provided the most stringent tests of mean field theory, a theory which is built upon the self-consistent motion of nucleons in quantum orbits and which forms the basis for most of our microscopic understanding of nuclear structure and reactions. In the last several years, considerable effort has also been directed at the reaction processes associated with a fundamental understanding of the nuclear force. For example, the currents generated by the exchange of mesons have been isolated. However, for all of these issues, the next level of understanding will be reached only with the availability of high intensity continuous beams.

Another direction under active investigation is that associated with polarization. Electrons, protons, neutrons and many nuclei have a property similar to that found in conventional bar magnets, namely, a directionality (north and south poles) and associated magnetization. When the particles in a beam or target are lined up, the beam or target is said to be polarized. Many important physics questions can be addressed only by organizing the beam electrons or the target nuclei or both in such a polarized condition instead of the usual randomly oriented condition. For example, fundamental quantities such as the charge distribution of the neutron or of the deuteron, the most elementary nucleus, and important tests of the electroweak theory remain elusive in the face of the technical obstacles which have so far prevented effective exploitation of polarization studies with intense electron beams. A polarized beam has now been developed at Bates, and some exploratory polarization studies are being advanced. This program is unique in the world. However, a full capability will be at hand only with the additional development of useful polarized targets.

The MIT-Bates experimental research program has supported a vibrant educational program (an NSAC report recently referred to "MIT's exceptional role in graduate training for nuclear physics"). About fifty Ph.D.'s have resulted from the program in the last decade, including Oppenheimer Fellows at Los Alamos, researchers in high-tech industrial environments, faculty at leading universities, etc. The new experimental initiative described below, in leading to novel forefront research possibilities, will sustain the success of the program in attracting and broadly training scientifically aggressive young researchers.

South Hall Ring

The research program outlined above has done much to frame the questions and to establish the experimental basis for the future electronuclear studies needed to advance nuclear physics along new directions. The new capabilities needed have been identified: continuous (CW) beams and full utilization of polarization observables. The South Hall Ring project at the Bates Laboratory is an experimental initiative which will provide these capabilities throughout the important energy range accessible to the existing accelerator (i.e., up to 1 GeV). It is very cost-effective ($14M over four years) and indeed will be funded as part of the ongoing nuclear physics base program. The ring will be an integral part of the South Experimental Hall using the previously mentioned "C" and "B" lines for experiments in the internal target mode and in the extracted beam mode, respectively (see Figure 5). This is accomplished by using the SHR to manipulate the time-structure of the pulsed beam provided by the accelerator. As already discussed, the needed detectors and polarized beam are available.

In the internal target mode, the electrons are circulated thousands of times through a windowless gas target introduced into the ring. The major benefit of this configuration is that it permits (and requires) the use of exceedingly thin targets, i.e., targets so thin that an insufficient number of interesting collisions would take place if each electron passed through the target only once. There are several advantages to this approach. One is that heavily ionizing reaction products are able to leave the target and reach the detector. This possibility is central to a number of planned experiments, for example, those aimed at a basic understanding of nuclear fission or of the propagation of pions in the nuclear interior. Perhaps the most exciting prospect, however, is that associated with polarization. Advances in laser technology and surface science now make it feasible to produce gases of polarized nuclei of sufficient thickness for internal target use. There is considerable activity in this field, for example, at Argonne, Caltech, Harvard, Indiana, MIT, Oak Ridge, Princeton and Wisconsin. Such internal target experiments, representing a significant departure from the traditional experimental configuration in electronuclear physics, will require innovative developments advancing both physics and technology. In considering potential developments at Bates, NSAC has stressed that the "combination of internal target capability and polarized beams for addressing important new areas .... will be unique in the world." Further, the program is totally complementary to that planned for CEBAF.

In the extracted beam mode, the SHR will be used as a pulse stretcher. The basic idea is that the SHR will capture each accelerator beam pulse and then "leak" the electrons to Beam Line B uniformly between pulses. The technical challenge lies in performing the filling and emptying procedures efficiently, rapidly, and yet smoothly. Again, we anticipate a program complementary to that at CEBAF, for example, in exploring nuclear collective motion, in mapping the nuclear spectral function, and in measuring the nuclear pion distribution near threshold. With the South Hall Ring experimental initiative at Bates and the major new facility at CEBAF, the American basic research community will have at its disposal unmatched capabilities built upon novel technologies.

Concluding Remarks

We are enthusiastic about our science, about the technical innovations we are pushing to realize that science, and about the new opportunities awaiting us. We are confident in the ability, drive, and future of the young scientists trained in our program. Nevertheless, I would be remiss in not mentioning that our efforts in the symbiotic research and educational enterprises remain hampered with the current level of operating funds. All facilities, university-based or at national laboratories, are significantly underutilized. Not only are the number and quality of experiments diminished, but the time-scale for any major experimental initiative is dragged out. This particularly disrupts the careers of young scientists, the graduate student eager to complete his apprenticeship with a significant piece of work, the young researcher trying to structure a career, the young faculty member working against a tenure clock. Clearly, we try to minimize the frustration and maximize the chances for these young people who, after all, are our future, but fiscal austerity inevitably extracts its scientific cost both today and in the supply of succeeding generations. Of course, we recognize the severe budgetary constraints and many competing needs before the Congress. Indeed, we are very appreciative of the support our field has received in this time of scientific opportunity but persistent budget deficits. The dedication shown by many in the government, both here in Congress and in the Administration, towards a strengthening of the nation's basic science research and training programs sustains our optimism in a vigorous scientific future.

TABLE 1

UNIVERSITY, LABORATORY AND INDUSTRIAL AFFILIATIONS OF PARTICIPANTS IN ACTIVE EXPERIMENTS
(January to December 1986)

Adelphi Technology
Alberta, University of
American University
Argonne National Laboratory
Bonn, University of
Boston University
Brookhaven National Laboratory
California Institute of Technology
California State at Los Angeles
Carnegie-Mellon University
Catholic University
CEBAF
City University of New York
Colorado, University of
Darmstadt, University of
Florida, University of
George Washington University
Glasgow, University of
Harvard University
Hughes Research Laboratories
Illinois, University of
Indiana, University of
Kent State University
Kentucky, University of
Lawrence Livermore National Laboratory
Los Alamos National Laboratory
Louisiana State University
Lowell, University of
Lund, University of (Sweden)
Mainz, University of (West Germany)
Manitoba, Unviersity of
Maryland, University of
Massachusetts, University
Michigan State University
Massachusetts Institute of Technology
Max Planck Institute (W. Germany)
Mount Holyoke College
National Bureau of Standards
Naval Research Laboratory
New Hampshire, University of
NIKHEF (Amsterdam)
Naval Surface Weapons Center (N.S.W.C.)
Northwestern University
Pennsylvania State University
Pittsburgh, University of
Princeton University
Rensselaer Polytechnic Institute
SACLAY (France)
Saskatchewan, University of
Scitex Corporation
South Carolina, University of
Stanford University
Syracuse University
Virginia, University of
Washington, University of
William and Mary, College of
Wisconsin, University of
Worcester Polytechnic Institute
Yale University

FIGURES

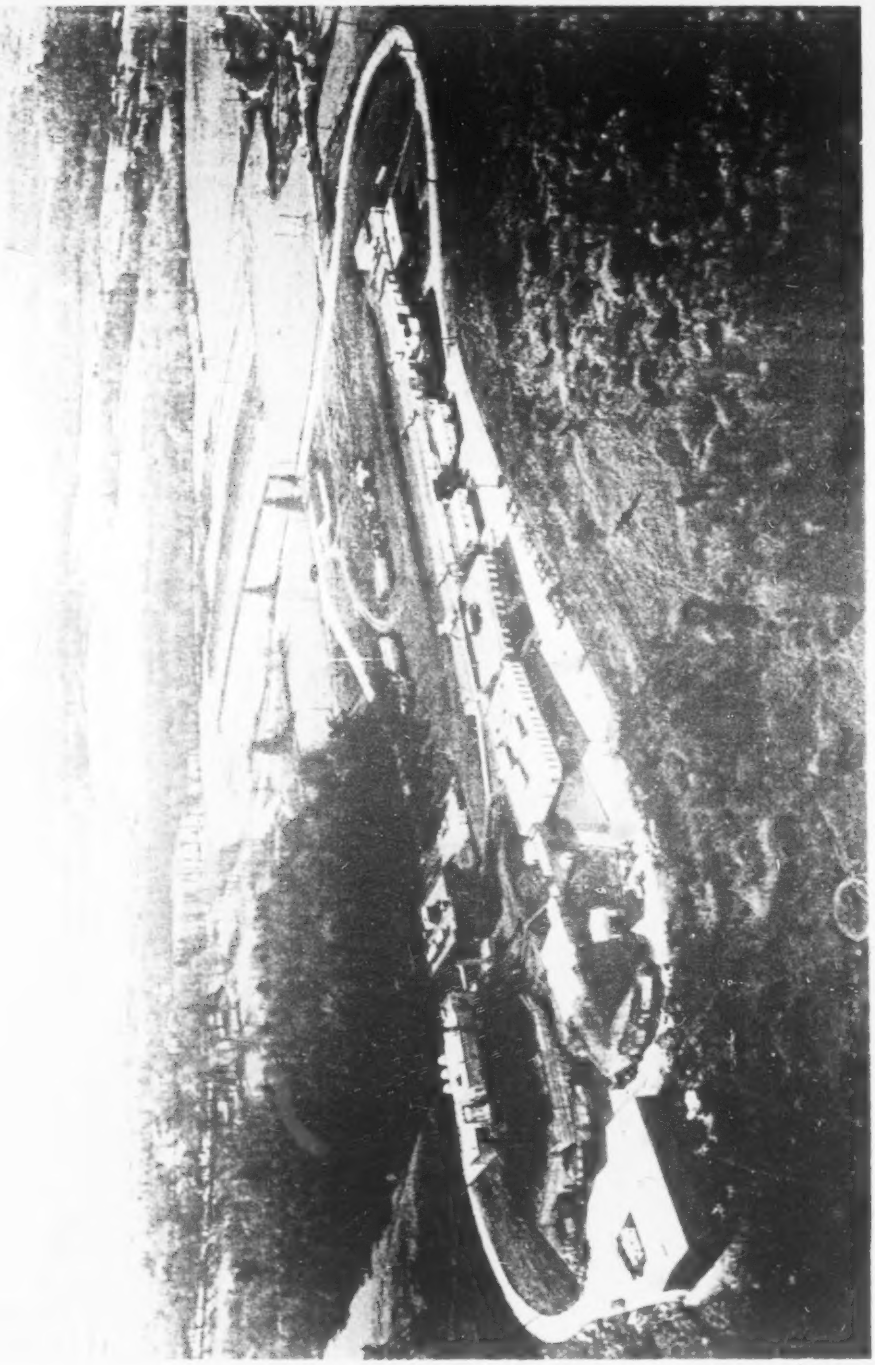
Figure 1. Bates aerial site photograph taken late in 1983. Long narrow structure at center houses the RF transmitter units which supply power to the accelerator, which is about 200 meters long. The partly earth-covered buildings at the left house the primary experimental areas.

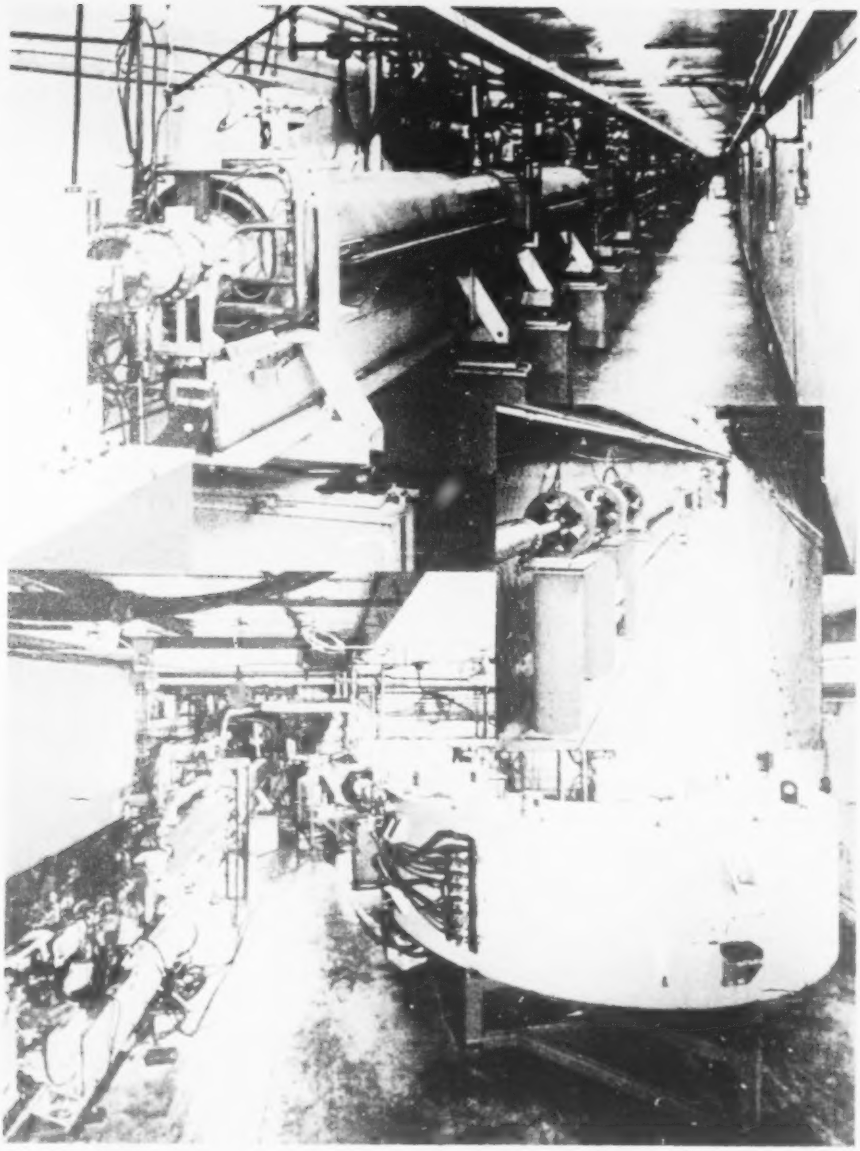
Figure 2. Accelerator/Recirculator System. Upper photo is a view of the accelerator as seen looking downstream from the injector. Lower photo shows the recirculator 180° return loop as it reconnects with the linac. Inset shows the recirculator return path which is located parallel to the linac vault. The recirculator represents a cost-effective method of doubling the available beam energy by passing the electrons through the accelerator a second time.

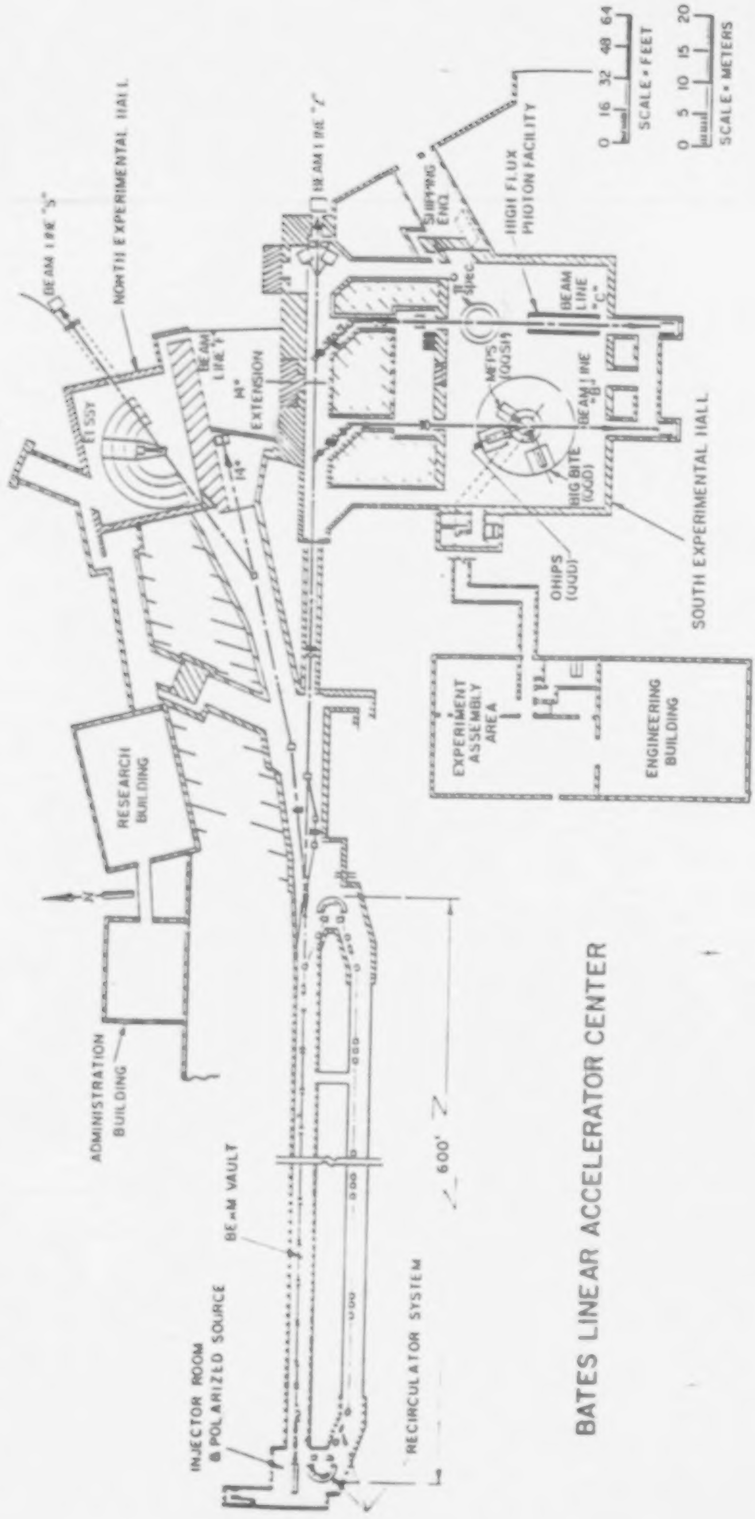
Figure 3. Current site plan (at beam level).

Figure 4. A view of the South Hall coincidence spectrometers, OHIPS (right), BIGBITE (center) and MEPS (left). Such detectors, weighing hundreds of tons, provide the essential capability needed to exploit continuous beams for basic research.

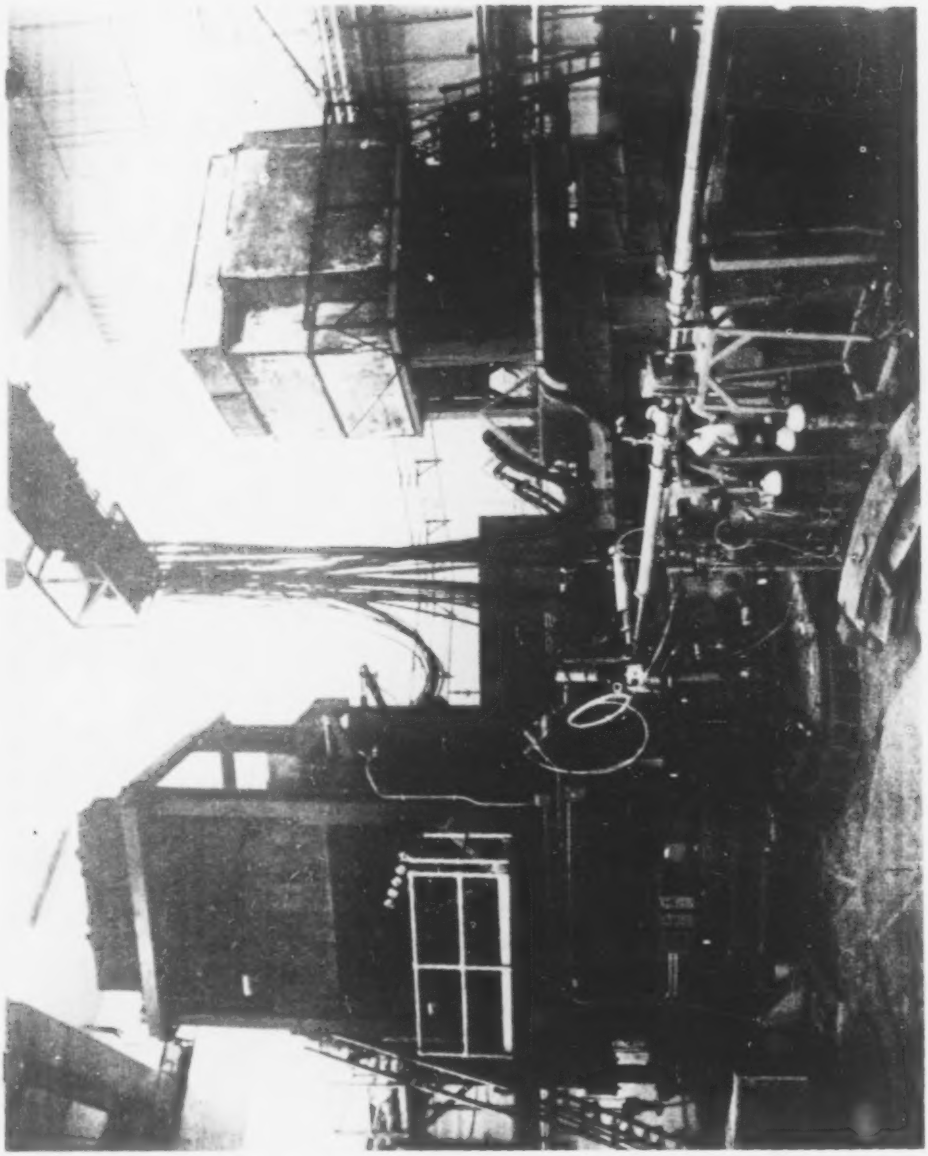
Figure 5. South Hall experimental area with the South Hall Ring.

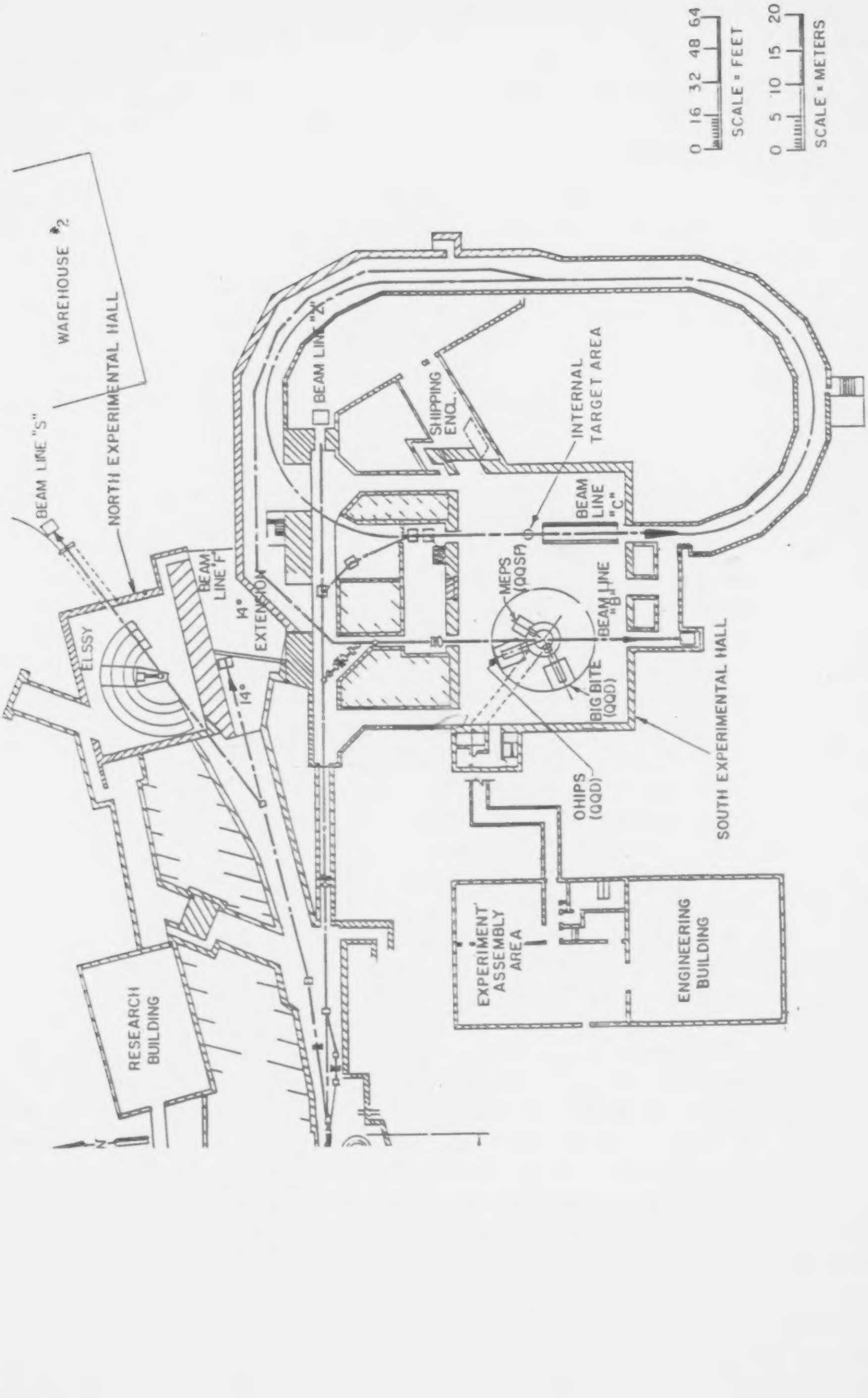





INJECTOR ROOM
& POLARIZED SOURCE
BEAM VAULT
RECIRCULATOR SYSTEM
600'
ADMINISTRATION BUILDING
N
RESEARCH BUILDING
ELSSY
NORTH EXPERIMENTAL HALL
BEAM LINE "S"
BEAM LINE "T"
14°
14° EXTENSION
BEAM LINE "Z"
SHIPPING ENCL.
HIGH FLUX PHOTON FACILITY
MEPS (OOSH)
BEAM LINE "B"
BEAM LINE "C"
BIG BITE (OOD)
OHIPS (OOD)
SOUTH EXPERIMENTAL HALL
EXPERIMENT ASSEMBLY AREA
ENGINEERING BUILDING
0 16 32 48 64
SCALE = FEET
0 5 10 15 20
SCALE = METERS

BATES LINEAR ACCELERATOR CENTER




WAREHOUSE #2
NORTH EXPERIMENTAL HALL
BEAM LINE "S"
ELSSY
BEAM LINE "F"
14° EXTENSION
14°
BEAM LINE "X"
SHIPPING & ENCL.
INTERNAL TARGET AREA
BEAM LINE "C"
MEPS (QQSP)
BEAM LINE "B"
BIG BITE (QQD)
OHIPS (QQD)
SOUTH EXPERIMENTAL HALL
RESEARCH BUILDING
EXPERIMENT ASSEMBLY AREA
ENGINEERING BUILDING
N
0 16 32 48 64
SCALE = FEET
0 5 10 15 20
SCALE = METERS

Mr. CHAPMAN. Thank you, Dr. Moniz. Dr. Garvey, you may proceed.

STATEMENT OF DR. GERALD T. GARVEY, DIRECTOR, CLINTON P. ANDERSON MESON PHYSICS FACILITY, LOS ALAMOS NATIONAL LABORATORY, LOS ALAMOS, NM

Dr. GARVEY. I welcome the opportunity to join with my distinguished colleagues to present to this Committee the present status and opportunities in nuclear and particle physics.

In particular, I will address the state of affairs at the Clinton P. Anderson Meson Physics Facility at the Los Alamos National Laboratory. This facility is more often referred to as LAMPF.

I think I will skip and just mention to you three main points and illustrate one of them. There are three main points I want to leave with you today.

The first is that LAMPF is a unique and powerful tool that supports a very broad spectrum of research. As such, it serves the needs of a large number of researchers.

Two, much of the research carried out at LAMPF deals with forefront issues confronting both nuclear and particle physics.

And three, we have an excellent plan which builds on what we have developed over the years to greatly extend the capability of LAMPF. This extension will allow the United States to sustain scientific leadership in several vital areas well into the next century.

The high intensity, which is the specialty at LAMPF, allows us to carry out world class research that's unique to our facility.

In the nucleon area we've just completed a system called NTOF. NTOF is an acronym for Neutron Time of Flight, which is the best way to measure a neutron's energy.

This new setup allows us to precisely study reactions in which an incident proton interacts with a nucleus and changes into a neutron. The energy of the outgoing neutron is measured by the time it takes it to transverse about a three eighths of a mile flight path.

And more importantly, we can vary the spin direction of the incident proton and measure the spin direction of the outgoing neutron, thus within a few years, the nuclear physics community will have a complete characterization of the spin and isospin nature of the nucleon-nucleus interaction.

Over in our meson-neutrino area, where a large number of muons are created by the powerful primary proton beam, those muons will be subjected to close scrutiny. A collaboration with 11 universities has been established to seek out the decay of a muon into an electron plus a gamma ray. This process should not occur if our inviolate standard model is absolutely correct.

However, physicists are unanimous in believing that the standard model is not the whole story, and that it must break down if further unification of the fundamental forces is to take place.

The only question is where we will encounter the first breakdown of the standard model. Several theoretical hypothesis suggest that looking for the decayed muon to an electron plus gamma, is an excellent place to start.

This new experiment should be running by 1989, and is a factor 500 times more sensitive than previous experiments. As you might well imagine, you have to look at a lot of muons searching for a process that you are looking for to occur at one part in ten million-million. LAMPF makes lots of muons.

The LAMPF neutrino program has emerged as an extremely potent activity. We are the only laboratory in the world to have observed, much less measured, the cross-section for electron-neutrinos to scatter off electrons.

The probability of this process occurring is correctly described by the standard model I mentioned earlier. In addition to what may be the world's most sensitive neutrino oscillation experiment, which is currently running, we realized about a year ago that we were in a unique position to measure a fundamental constant of nature, the sine squared to the Weinberg angle.

This makes unique use of a facility that we have at Los Alamos. It's an experiment involving, again, about 10 universities. It's an expensive experiment, but very high on our priority list. The Department of Energy and the Laboratory are looking at the cost at the present moment. We certainly hope that it is approved to move in 1990. It's a high priority at LAMPF.

Now, looking at the longer term, we believe that nuclear physics will require access to a high intensity proton facility with an energy some 30 to 100 times the energy now available at LAMPF.

Such a facility is referred to as a kaon factory, because it will make available more kaons in a single day to an experimenter, than is available in the whole world in a year.

There are two scientific thrusts that drive this need. First is the need to understand quantum chromodynamics, the theory of strong interactions, at length scales appropriate to nucleons, mesons, and real nuclei.

Unfortunately, quantum chromodynamics is only applicable at energies far above those encountered in conventional nuclear matter.

And secondly, the question of investigating how the standard model must be extended, drives physicists to design evermore penetrating investigations of rare, or forbidden, decays.

To do this requires providing evermore intense and pure beams of weakly decaying particles and neutrinos. The rare decay searches allow scientists a look at mass scales far beyond what can be achieved with the highest energy colliders now envisioned.

The great importance of the broad program of physics that can be carried out at such a kaon factory, has led to five initiatives throughout the world to create such a facility.

LAMPF would be an excellent injector for such an advanced hadron facility. In fact, it's the best in the world. If I could just show the first figure; that shows a half mile long linear accelerator, known as LAMPF, coming down into its complex experimental area. And if you could show the next transparency, this shows basically how we would take the beam out of LAMPF, increase it to about 1.6 GeV, provide research for both neutron and neutrino physics.

The neutron area would facilitate studies in condensed matter. And then, a smaller fraction of the beam is first brought up to 15 GeV, and then finally brought up to 60 GeV, and led into experimental areas, much of which is in place.

That is simply to show you how a facility of that kind fits on the LAMPF mesa. The LAMPF accelerator, if you could find it, John, is shown coming down there, showing how this facility is to be used.

As I said, this plan that we have would allow the use of more than $2 million worth of existing infrastructure. It allows us to provide a world class pulsed neutron facility to greatly extend the current activity, called LANSCE, as well as to build the ideal kaon factory.

U.S. science would be magnificently served with such a facility well into the next century. The LAMPF program, if I can conclude, is an important element of the whole activity at Los Alamos.

It's the largest basic research program at the Laboratory, and its user mode of operation couples the Lab in a strong and positive way to the outside basic research community.

The Director of Los Alamos, Sig Hecker, believes these facilities are absolutely essential to a healthy laboratory in an open society such as ours.

Hence, it is likely in the best interest of science and this country to locate an advanced hadron facility at Los Alamos sometime in the next decade.

[The prepared statement of Dr. Garvey follows:]

Statement to the House Committee on Science, Space, & Technology Subcommittee on Energy Research and Development

DOE FY 1989 Budget Request for General Science and Research Programs

Gerald T. Garvey
Director
Clinton P. Anderson Meson Physics Facility
Los Alamos National Laboratory

March 30, 1988

I welcome this opportunity to briefly discuss the status of the Los Alamos National Laboratory's Clinton P. Anderson Meson Physics Facility, often referred to as LAMPF. Your support of basic research plays an essential role in the success of our endeavors. I would like to invite the members of this Committee to visit LAMPF at their convenience to observe first hand part of the great return on the nation's investment in our science.

Today I wish to convey three main points to you:

(1) LAMPF is a unique tool for nuclear science research. It produces the world's most powerful proton beam and has the largest user group for carrying out research in nuclear physics.

(2) A vigorous and broad research program is carried out with significant achievements throughout the field of nuclear physics and significant contributions in other areas, such as medical isotope production and condensed matter physics.

(3) Our long-range planned facility upgrade will enable the country to continue advancing the frontiers of nuclear physics well into the next century.

In the evolution of nuclear physics, three basic types of accelerators have proven essential. Electron, heavy ion, and proton facilities have all revealed unique and complementary aspects of nuclear matter; each will continue to play a unique role. Proton facilities have research programs with the broadest scope because the high-intensity proton beam allows the creation of useful secondary beams of subnuclear particles--mesons, muons, and neutrinos. These secondary beams have unique properties essential to developing a complete picture of the fundamental interactions as well as the properties of the matter at the heart of the atomic nucleus. Among all the nuclear physics facilities in the world, LAMPF generates the most intense primary beam of protons.

A. The Facility

The heart of LAMPF is an accelerator one-half mile long. It simultaneously accelerates both protons (H^+) and hydrogen atoms with an added electron (H^-) to an energy of 800 million electron volts. The facility is designed to bridge the gap between nuclear and subnuclear physics as well as to be used for practical applications. A photograph of LAMPF is shown in Fig. 1. The experimental area is in the center of this picture. The underlying complexity of this experimental area is shown in Fig. 2, which illustrates the diversity of particle beams and experiments that are made possible by the extremely powerful primary beam.

The experimental area is designed so that many experiments can be carried out at the same time. A 1-milliampere H^+ beam, the most intense beam of any accelerator in the world (Fig. 3), creates beams of secondary particles (pions and muons) at targets A-1 and A-2. The H^+ beam then coasts to the beam stop area where large numbers of neutrinos (neutral elementary particles) are produced and studied with large sophisticated detection systems. There are three experimental areas for studying pions and one for studying muons, which are products of pion decay.

Simultaneously, two H^- beams are accelerated and routed to different areas. One goes to the nuclear physics area and the other to the Los Alamos Neutron Scattering Center (LANSCE). This latter beam represents 10 percent of the LAMPF capability and is used, in conjunction with a proton storage ring, to produce intense pulses of neutrons, primarily for condensed matter research. This 10 percent is sufficient to make LANSCE a world-class neutron spallation source. The H^- beam sent to the nuclear physics area may be polarized and is used for studies of the nucleon-nucleon interaction and the interaction of nucleons with nuclei. Thus, there are ten to twenty experiments being carried out simultaneously throughout the LAMPF complex when the beam is being delivered.

The accelerator provides beam for research for 3000 hours each fiscal year, although the tight funding since 1986 makes this difficult. Similar to most operating facilities, we experienced some expansion of resources in the early 1980s. The Gramm-Rudman-Hollings budget reduction in FY 1986 caused a precipitous drop in our funding, which led to an 8-percent reduction in staff. In the subsequent years 1987 to 1989, the pressure of building new facilities elsewhere in the Department of Energy (DOE) nuclear physics program has constrained the LAMPF budget to levels that do not keep pace with inflation. However, we are emphasizing cost-effectiveness in both operations and experiment support and are presently managing to carry out our highest-priority activities. If the operating budget falls significantly below its current level in subsequent years, it would threaten the viability of our research program.

As you might imagine, a facility with such diverse capability has a very large and active group of involved scientists. The statistics of our medium-energy physics user program are shown in Table I. Our users are a vigorous group of scientists from 118 institutions, by far the largest group at any nuclear physics facility in the world. LAMPF was described in the most recent DOE review of the U.S. program as "the flagship of nuclear science." We are to be reviewed again this year and fully expect to have that status reaffirmed.

We are able to employ residual portions of the LAMPF beam at no additional cost to nuclear physics but with great benefit to the nation. LAMPF allows research at the forefront of condensed matter science, biology, medicine, and national security to go forward. In this past year, as indicated in Table II, we supported the research of more than 450 scientists carrying out more than 200 experiments.

In nuclear physics we support some large general-purpose experimental devices that enable unique research. As an example, Fig. 4 shows the High Resolution Spectrometer (HRS) that allows a scientist to measure (with a precision of better than one part in ten thousand) the energy given up by a proton to excite a nucleus. This precision, coupled with the ability to fix the direction of the proton spin, allowed LAMPF to be the first laboratory in the world to provide data showing the great advantage of employing a relativistic ~~wave~~ equation to describe the spin-dependent interaction between a nucleon and the nucleus. LAMPF also has the world's highest-resolution facility, denoted EPICS, for the study of pion-nucleus interactions. The existence of facilities like HRS and EPICS at LAMPF allows small research groups to perform world-class experiments.

B. Present and Near Future

The LAMPF program today is more vigorous than ever with new important nuclear physics experiments being put in place.

The LAMPF research program is aimed at increasing understanding of the intrinsic characteristics of the basic interactions among elementary particles--strong and electroweak--and the role played by these interactions in nuclear physics phenomena. The strong interaction is being studied in the nucleon physics laboratory for which a new Neutron Time-of-Flight capability has just been completed. It will have a 3/8-mile-long flight path and will allow the study of the *(p,n)* charge exchange reaction with unprecedented resolution over the entire range of LAMPF energy (200-800 million electron volts). A sophisticated detection system allows the researcher to also determine the spin direction of the outgoing neutron. In addition, LAMPF has developed the capability of fixing the spin direction of certain nuclear targets and will bring a new intense polarized ion source into operation in 1989. Thus, scientists will be able to completely specify the spin dependence of the interaction. By the early 1990s, the scientific community should have obtained an excellent characterization of the spin-isospin modes of nuclear excitation as well as the medium effects on the nuclear interaction within the nucleus.

The elementary particles and their electroweak and strong interactions have been organized into a single scheme, termed the Standard Model, which is consistent with all available experimental results. However, this model does not include gravity and is not a complete unified description of particle physics. All theoretical attempts to extend the Standard Model predict new phenomena, and it is critically important to experimentally test the model to determine which extensions are correct.

In a very ambitious experiment, a collaboration of eleven universities will seek to measure the process in which a muon decays into an electron plus a gamma ray ($\mu \rightarrow e\gamma$). This process is forbidden to occur within the context of the Standard Model and has not been observed to occur at a level of a decay of this type per 200 billion (2×10^{11}) normal muon decays ($\mu \rightarrow e\nu_e\nu_\mu$). However, some extensions of the Standard Model imply that such a decay may, in fact, occur. This new experiment, called MEGA, will be 500 times more sensitive to the electron plus gamma decay mode than the previous measurement. Needless to say, observation of such an effect would be of enormous importance and would represent the first observation of a process not permitted by the Standard Model. Until such breakdowns are found, physicists will not know which of the many possible directions represent the correct extension of the Standard Model.

As an example of applications-oriented research, a collaboration involving Brigham Young University, Idaho National Engineering Laboratory, and Los Alamos has been studying the reaction sequence in which a negatively charged muon is captured in a *d-t* molecule. The muon acts like a heavy electron and serves to shield the repulsive Coulomb field between the *d-t* nuclei. This allows *d-t* fusion to occur, generating an alpha particle and a neutron with a 17-million-electron-volt energy release. Although the muon lives only two-millionths (2×10^{-6}) of a second, it has been observed at LAMPF that, under appropriate conditions, each one can be made to cause an average of 150 fusions before decaying. This number is appreciably more than expected, and further research is being invested in understanding the limits to this remarkable phenomenon. Others at Los Alamos and elsewhere are investigating the possible use of this process in an actual energy generation system.

The neutrino research program at LAMPF has been gathering considerable momentum over the past few years. The probability for the scattering of an electron neutrino from an electron has been measured at LAMPF. It shows that the interference between the Z^0 and $W^{\pm}$ vector bosons, which uniquely enters this process, is destructive as predicted by the Standard Model. This interference is of great importance in a variety of astrophysical phenomena. We are now conducting a sensitive search to see if any of the neutrinos (ν_μ, $\bar{\nu}_\mu$, ν_e) created in our beam stop can change into an electron antineutrino ($\bar{\nu}_e$). This phenomenon, termed neutrino oscillation, is not possible in the Standard Model but is predicted to occur in many versions of more unified theories. We have as yet found no evidence for this process but have such a sensitive experiment that we will continue to search into previously unmeasured domains.

Over the past two years it has been realized that using the short bursts of neutrinos from the beam produced with the proton storage ring, a precision measurement could be carried out of a fundamental quantity, the sine squared of the Weinberg angle ($\sin^2 \theta_W$). It is crucial to the electroweak theory that the value of this quantity be correctly accounted for in physical processes at vastly different energies. The proposal for this multimillion-dollar experiment has been reviewed for scientific and technical merit by an external peer review committee convened by DOE and was strongly endorsed. The detailed costs and schedules are being examined and we expect to receive approval from the DOE to proceed. This experiment has a very high priority at LAMPF.

In addition, LAMPF supports some interesting applied physics programs. As mentioned earlier, LANSCE is just beginning to provide the U.S. materials science community a world-class pulsed neutron source at reasonable cost to the basic research community. The Congress and the Basic Energy Sciences program in DOE have provided $17 million to construct a new experimental hall, which will be completed this spring to allow effective use of this new capability, particularly in the area of condensed matter physics. Furthermore, the LAMPF beam can be used to produce radioisotopes for medical pharmaceuticals and other applications. LAMPF is the only source in the world of the following isotopes: Be-7, Al-26, Sc-44, V-48, Br-77, Y-77, Ag-105, Ag-109, Cd-109, Hf-172, Ho-163, and Lu-172.

C. The Distant Future

In the more distant future (1992-1993), I am convinced that the U.S. nuclear physics community will require access to a *high-intensity* proton facility with energies 30 to 100 times that now available at LAMPF. Such a world-class facility has been referred to as an advanced hadron facility. The need for an advanced hadron facility is driven by two scientific thrusts. The first is understanding the implications of quantum chromodynamics (QCD) for the world of hadrons. Hadrons, such as protons, neutrons, kaons, and antiprotons, are the physical manifestations of quarks (the elementary particles that undergo strong reactions). The QCD theory, while likely the correct theory of strong interactions, is notoriously difficult to implement on the length scale where physical hadrons (particles observed in the real world) actually occur. The difficulty is specifically associated with the manner in which the "color" (analogous to charge in electromagnetic interactions) of quantum chromodynamics is actually confined to the hadronic interior. Further, great uncertainty exists regarding the "colorless" objects that can be formed out of quarks and gluons, the elementary objects of QCD.

The second major research area for an advanced hadron facility is the careful study of the properties of the copious numbers of weakly decaying particles and neutrinos that will be produced. Precise study of these particles and neutrinos may reveal the way in which the present-day Standard Model will have to be extended if a theory of all fundamental physical processes is to be developed. In this latter sense, the research is complementary to the superconducting super collider effort.

A long-range plan for the U.S. basic research program in nuclear physics was formulated in 1983. This plan assumed that the higher-energy and higher-duty factor electron accelerator project, the Continuous Electron Beam Accelerator Facility (CEBAF), that had been selected that spring would proceed to construction in an expeditious manner. The 1983 plan stated that the highest priority for new construction was to provide a large increase in the energy of heavy ions by the construction of a collider that is now being proposed in the form of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. We are now addressing the FY 1989 budget, with the delays in the implementation of that 1983 long-range plan painfully evident to all parties. The distress caused by these delays extends not only to scientists whose contributions and careers depend on these new facilities and those laboratories charged with building these high-priority facilities on far from optimal schedules, but also to those parts of the scientific community who see additional facilities required for a sound scientific future. For example, the need for a sizable increase in energy of the world's high-intensity proton facilities has become evident.

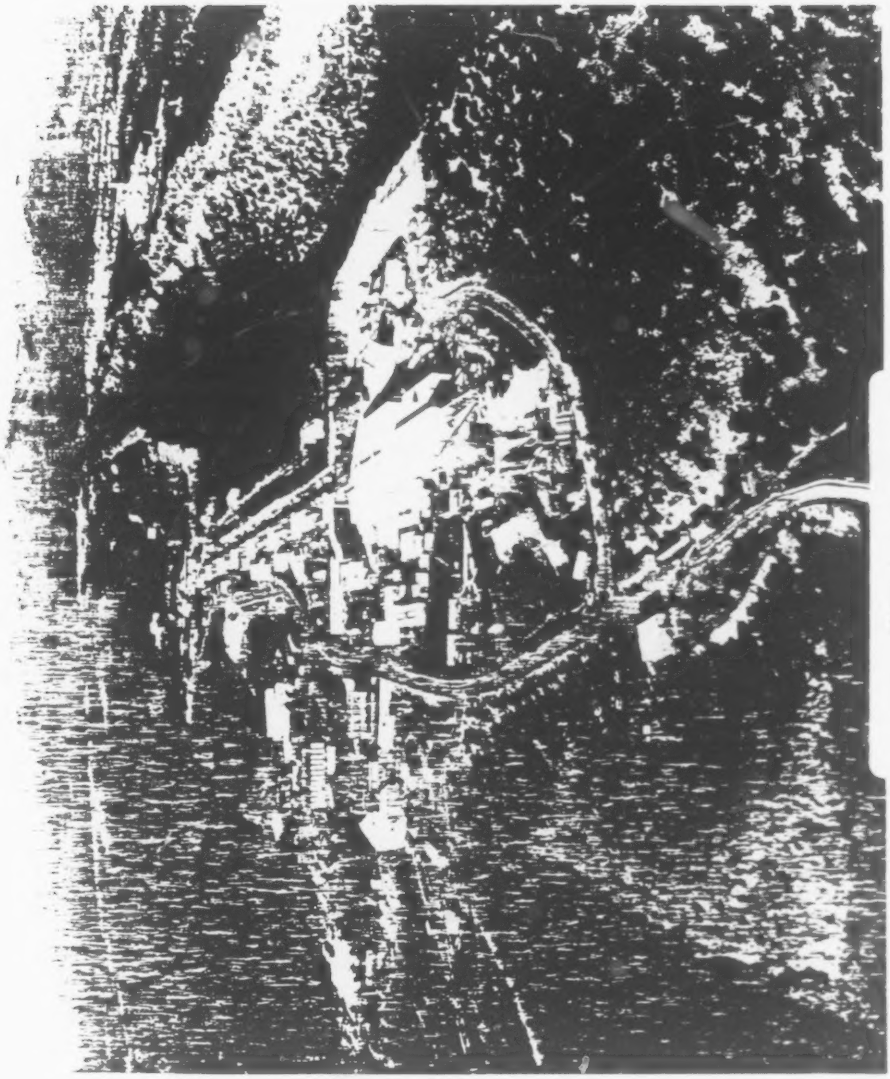
Canada, among several other countries, is also very interested in an advanced hadron facility. The Canadians propose an upgrade of the TRIUMF facility to the status of a kaon factory (KAON). Because of the expense of the upgrade and Canada's limited resources, the Canadians are seeking international involvement in the construction of KAON. The cost of the facility is estimated at $550 million (Canadian) ($440 million in U.S. dollars). The United States is being asked to provide $75 million over five years on the grounds that at least half of the users of such a facility would be from U.S. institutions. Although this form of collaboration might appear as a bargain for those unfamiliar with science on this scale, such an undertaking actually would not be very satisfactory on several counts.

In the first instance, it must be understood that, at present, Canada invests a total of $40 million (Canadian) in nuclear and particle physics. They estimate that the operating cost for such a facility is some $80 million (Canadian) ($64 million in U.S. dollars). Hence, Canada will have to increase its nuclear and high-energy physics expenditure by 200 percent merely to operate this single facility. Will they have the resources required to run a first-class facility? How responsive will they be to the priorities of the U.S. nuclear physics community, quite a different constituency than they have to appeal to in Canada? These are difficult questions and should be carefully investigated within the U.S. scientific community. A much more effective approach would be for the Canadians to contribute to a U.S. effort.

The present LAMPF accelerator is an excellent injector, in fact the best in the world, for such an advanced hadron facility and, when coupled with our experience and expertise in handling high-power beams, makes Los Alamos a natural place to site this next-generation facility. Siting the advanced hadron facility at Los Alamos will take advantage of the existing carefully developed infrastructure and ensure the continued health of adjacent facilities such as LANSCE. Figure 5 shows a conceptual layout of what such a facility would look like on the LAMPF site. At Los Alamos, the advanced hadron facility would be readily accessible to the U.S. nuclear physics community.

As you are probably aware, LAMPF plays a vital role in the technical and intellectual life of Los Alamos National Laboratory. It is a major link to the outside scientific community and provides a powerful technical base of people and hardware that has spawned many activities throughout the Laboratory. The health of LAMPF is an important element in the overall capability of the Laboratory to carry out its national security mission. The Laboratory must evolve its program mix to continue to ensure the nation's nuclear deterrent in a world of reduced weapons, while broadening its conventional defense technology role. First-class basic research facilities will continue to be crucial in enhancing scientific vitality.

Thus, I believe that the advanced hadron facility upgrade to LAMPF is in the general interest. Such a facility will enable the country to continue advancing the frontiers of nuclear physics well into the next century. Hence, for a host of scientific and policy reasons, the United States should commit to building an advanced hadron facility starting circa 1993 as the next major nuclear physics facility after CEBAF and RHIC.



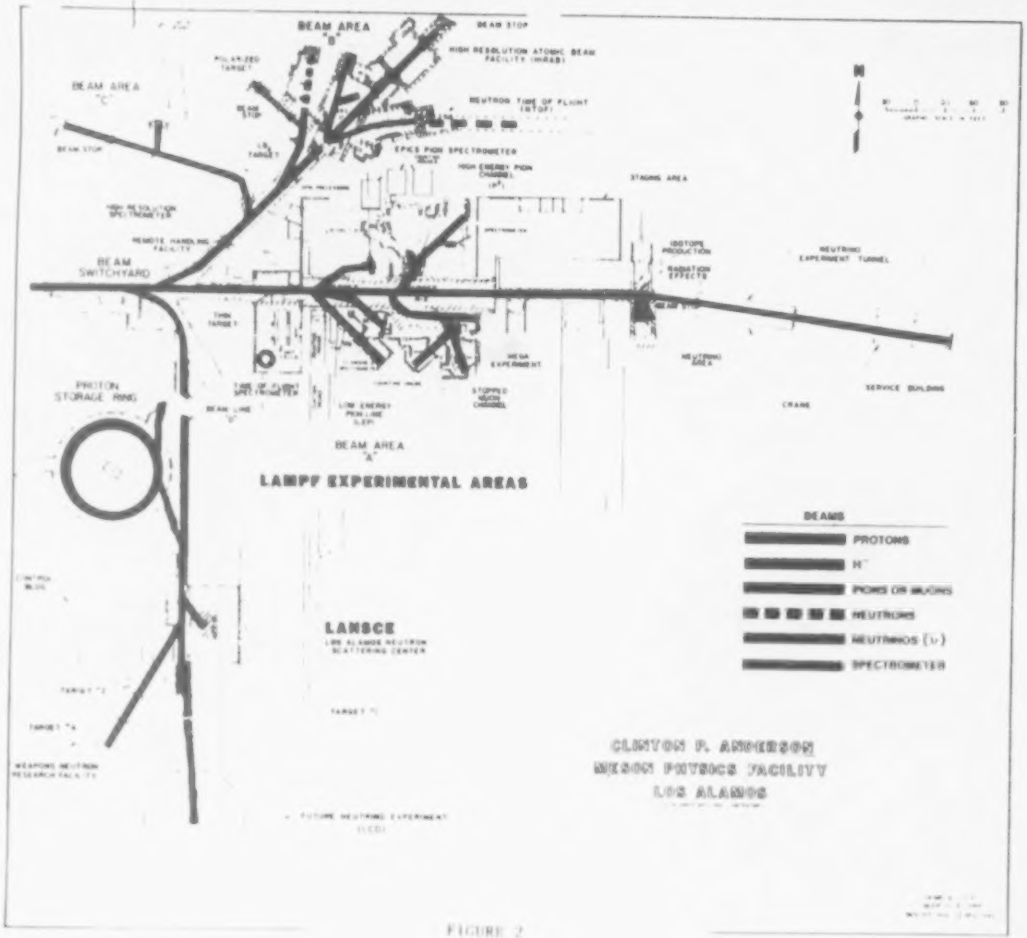
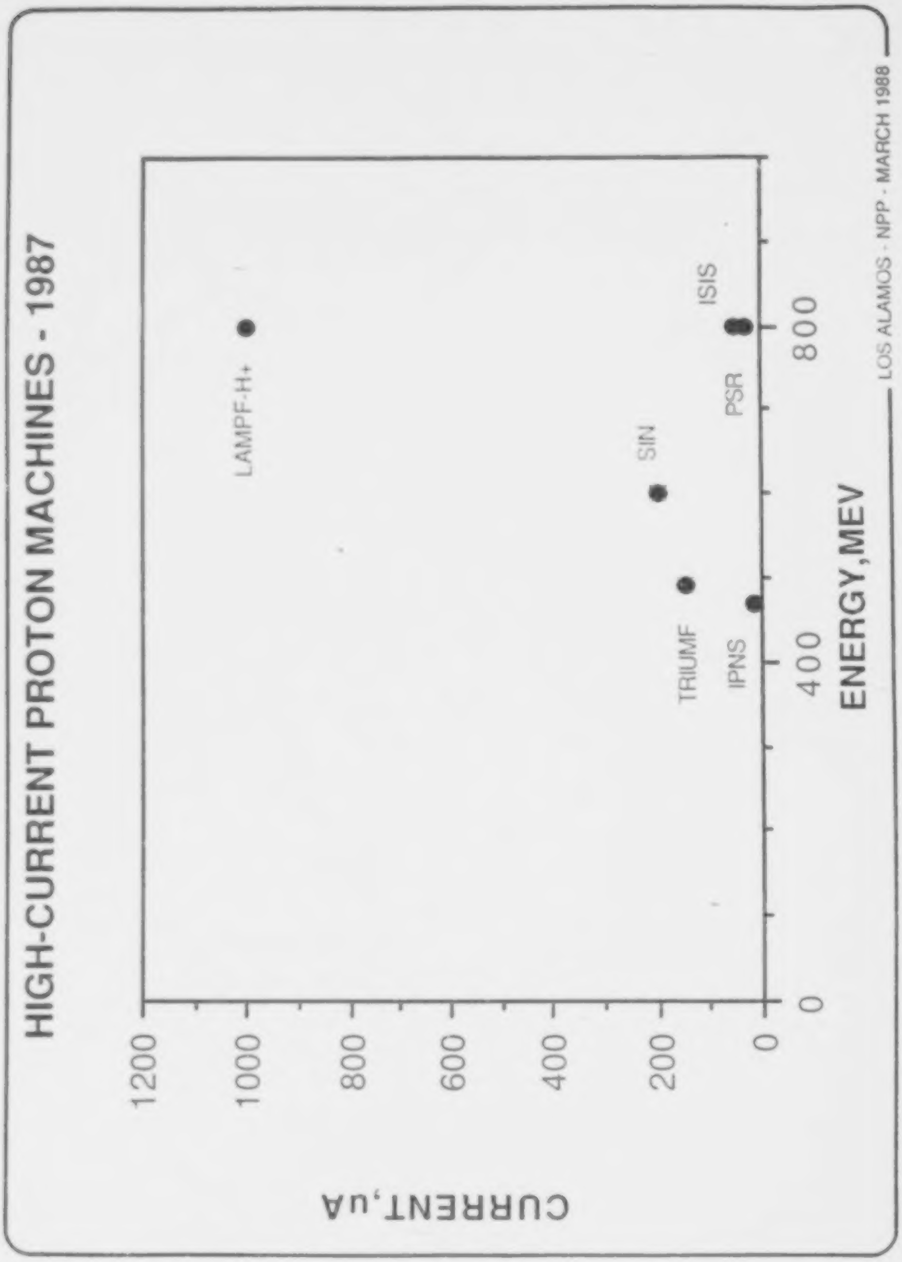

BEAM AREA "B"
BEAM STOP
HIGH RESOLUTION ATOMIC BEAM FACILITY (HIRAB)
POLARIZED TARGET
BEAM AREA "C"
BEAM STOP
NEUTRON TIME OF FLIGHT (NTOF)
EPICS PION SPECTROMETER
HIGH ENERGY PION CHANNEL (P³)
LD₂ TARGET
HIGH RESOLUTION SPECTROMETER
REMOTE HANDLING FACILITY
BEAM SWITCHYARD
STAGING AREA
ISOTOPE PRODUCTION
RADIATION EFFECTS
NEUTRINO EXPERIMENT TUNNEL
BEAM STOP
THIN TARGET
TIME OF FLIGHT SPECTROMETER
LOW ENERGY PION LINE (LEP)
STOPPED MUON CHANNEL
NEUTRINO AREA
SERVICE BUILDING
CRANE
PROTON STORAGE RING
BEAM LINE "D"
BEAM AREA "A"
LAMPF EXPERIMENTAL AREAS
BEAMS
PROTONS
H⁻
PIONS OR MUONS
NEUTRONS
NEUTRINOS (ν)
SPECTROMETER
CONTROL BLDG.
LANSCE
LOS ALAMOS NEUTRON SCATTERING CENTER
TARGET 1
TARGET 2
TARGET 4
WEAPONS NEUTRON RESEARCH FACILITY
FUTURE NEUTRINO EXPERIMENT (LCD)
CLINTON P. ANDERSON
MESON PHYSICS FACILITY
LOS ALAMOS
N

FIGURE 2



HIGH-CURRENT PROTON MACHINES - 1987

LOS ALAMOS - NPP - MARCH 1988

LAMPF USER STATISTICS
Nuclear Physics
FY 1987

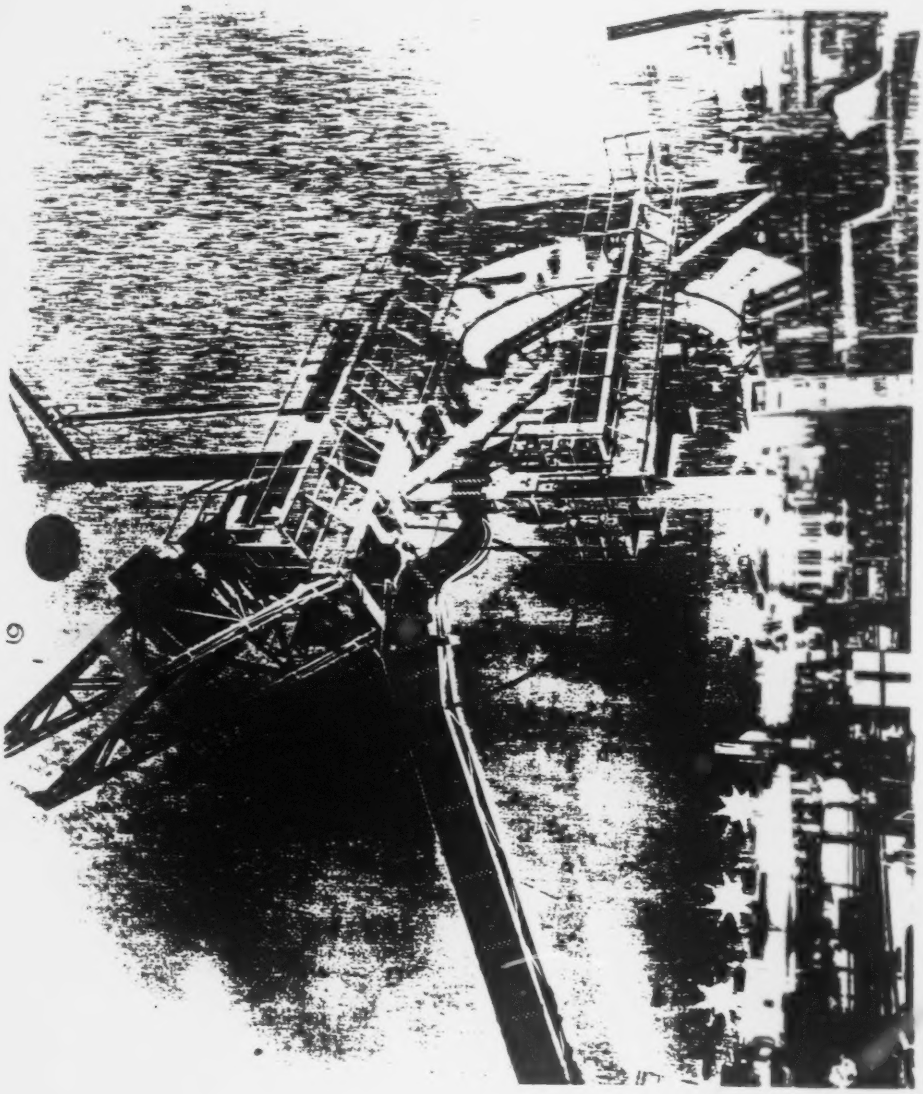
65	Experiments Received Beam in 1987
355	Scientists Participated in 1987
125	Experiments in Active Status
551	Participants in Active Experiments
118	Institutions Represented (35 Foreign)
1114	Proposals Submitted since 1971
581	Experiments Completed
121	Ph.D.'s Based on LAMPF Research
970	Members of LAMPF Users Group

TABLE I

LAMPF BEAM USAGE IN 1987

LAMPF RESEARCH PROGRAM (Nuclear Physics)	
Number of Experiments	65
Number of Participating Scientists	355
LOS ALAMOS NEUTRON SCATTERING CENTER	
Number of Experiments	128
Number of Participating Scientists	68
WEAPONS NEUTRON RESEARCH	
Number of Experiments	27
Number of Participating Scientists	54
NEUTRAL PARTICLE BEAM PROGRAM	
Number of Experiments	2
Number of Participating Scientists	15
ISOTOPE PRODUCTION PROGRAM	
Number of Isotopes	15
Number of Shipments	154
Number of Receiving Institutions	58

TABLE II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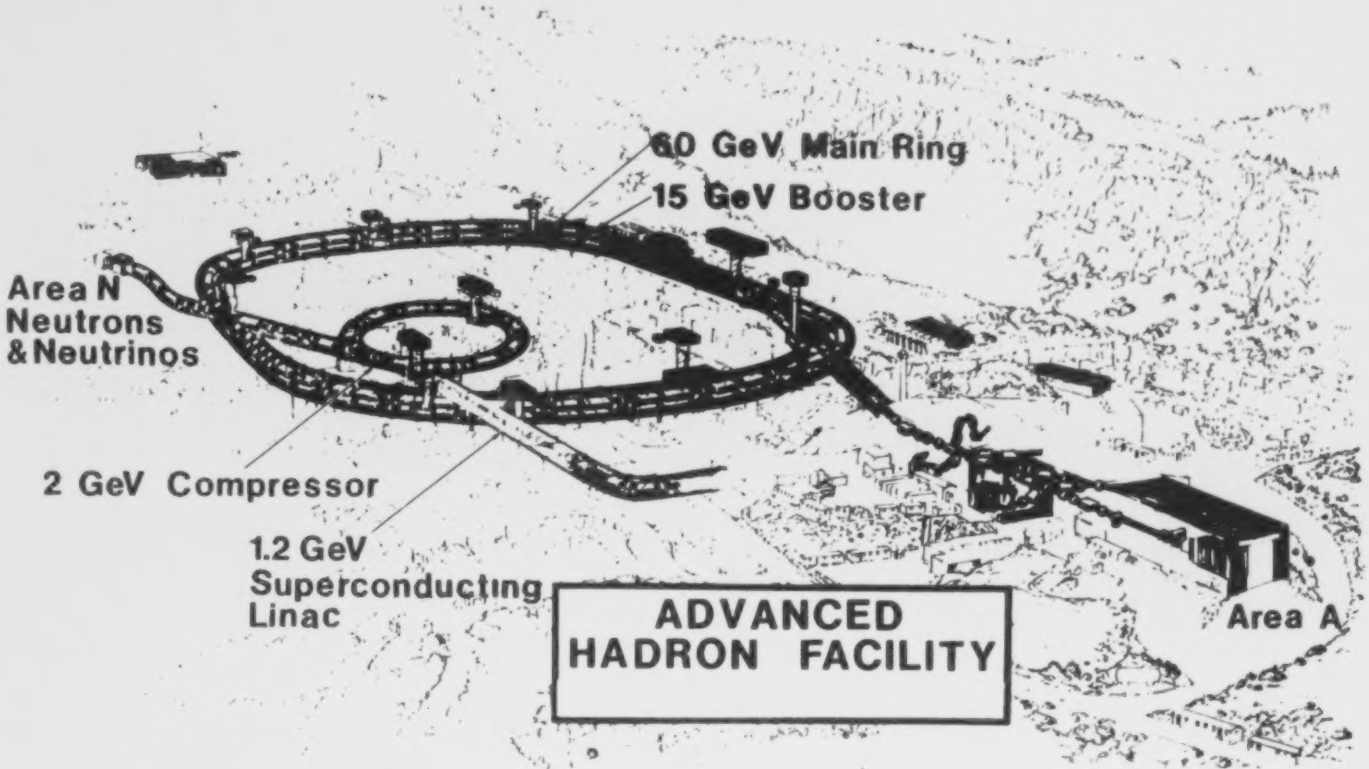

60 GeV Main Ring
15 GeV Booster
Area N
Neutrons
&Neutrinos
2 GeV Compressor
1.2 GeV
Superconducting
Linac
ADVANCED
HADRON FACILITY
Area A

FIGURE 5

PANEL 4 DISCUSSION

Mr. CHAPMAN. Thank you, Dr. Garvey. Let me just ask you a couple of questions, because we must conclude the hearing.

Professor Moniz, let me ask you. In your testimony you indicate that operating funds for the Bates laboratory are insufficient to adequately support research in educational enterprises undertaken at the Lab.

What, in your estimate, would be an appropriate operating budget for your laboratory. And what would be an appropriate annual growth rate for that operating budget?

Dr. MONIZ. Well, in the sort of steady-state operations, an additional $2 million per year would be the kind of budget which would allow full utilization and a full program of attracting grad students and training them in a reasonable and timely way.

Now, I mentioned the initiative which we are currently pursuing in the South Hall. This is an example of the kind of base experimental initiative, which, given the current fiscal austerity, requires us to make the same kinds of choices you were asking about earlier on a larger scale, in terms of pursuing future capabilities at the expense of current operations.

So, basically, in our current situation, increments on the order of $3.5 million would allow both a good training program and new developments. In the longer term, on the order of, say, $2 million per year. It's the kind of level which would allow full utilization.

I may just add, if I'm permitted, that, to be straightforward, similar problems do exist, of course, at other of the university-based laboratories. For example, there have been recent upgrades at Yale and at Seattle. And I believe they are in a similar situation of not being able to fully engage in their programs.

Mr. CHAPMAN. Dr. Garvey, we've had some discussions with representatives from Canada who have indicated that there is a desire to perhaps build a kaon factory at their triumpf facility in British Columbia. If we were to enter into some type of cooperative agreement with Canada on this facility, tell us how that would impact operations at Los Alamos.

Mr. GARVEY. It appears to me that the initiative on the part of the Canadians demonstrates the vital interest that exists in this area of physics. I think there are a variety of technical concerns that the scientific community, for the most part, has to worry about.

Many users find it attractive and believe that they might be able to get their experimental programs running sooner at Triumpf than at the upgrade of LAMPF that I alluded to in my presentation. I think it would have a very interesting impact on the LAMPF program in the long run, if the kaon factory were built in Canada. Much of the scientific case for proceeding with the upgrade of LAMPF, I think, would be somewhat preempted.

I think it's appropriate to worry about the quality of the science. In which case, I think LAMPF, being a superior injector, would lead to a better over-all facility.

Second, I would have a concern in this case that is somewhat different from the SSC, and it's the following. The Canadian nuclear and particle community is a small one. So, it is, in my mind, unlikely that they would use even a half of the existing capability of their kaon factory.

It is a potentially unstable situation, unless we work out our international scientific politics in a better way than we have. It's unlikely that the Canadian government, who is being asked to assume the full responsibility for running this facility, would be enchanted with the idea of a, roughly, $90 million operation with more than half the users coming from outside their country. It is potentially unstable, unless we do more in this area of international collaboration than we've done up to now.

Mr. CHAPMAN. Gentlemen, I would like to thank you again for your testimony today. We appreciate your attendance here, and appreciate the work that you do.

In a way, it's a little distressing, I guess, to think that, because of tight budgetary times, we hear a consistent theme of how much more could be done, resources being available. But at the same time it's rather exciting to see that we are in an era, it appears, that we are learning more every day. And that's exciting, as well.

We appreciate your participation and work in that area.

[Questions and answers for the record follow:]

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

Hearing on the Department of Energy (DOE)
FY 1989 Authorization Request for General Sciences Programs

Questions for the Record
Professor Ernest J. Moniz
Massachusetts Institute of Technology

March 30, 1988

1.-- It is our understanding that the Department of Energy has approved funds to upgrade the Bates facility.

   -- Could you discuss this in some detail?

   -- What is the funding level of this upgrade as proposed for FY 1989?

   -- Do you judge this funding level to be adequate to meet the future needs of the laboratory to sustain a strong and dynamic nuclear physics program?

2.-- Please discuss the relationship of Bates to the Continuous Electron Beam Accelerator facility described by Dr. Grunder who also testified on March 30th.

   -- How would you describe the cooperation between the CEBAF program and your laboratory?

Response

1. The South Hall Ring (SHR) experimental program at Bates, by introducing the possibility of internal target use with intense electron beams, will permit scientists to study the scattering of polarized electrons from polarized atomic nuclei. This has never been done. Several important experimental goals will be pursued with internal targets; examples are: measurement of the neutron charge distribution and of the deformation of "elementary" particles; the distribution of low energy pions in the nucleus; elucidation of the processes governing nuclear collective motion, such as fission; precise measurement of the structure of the deuteron, the most elementary nucleus. The SHR will also produce a nearly continuous extracted beam.

   The SHR will be an integral part of the existing South Experimental Hall. It will accept the pulsed electron beam from the existing accelerator (maximum energy of 1 GeV) and, in the internal target mode, will circulate the electrons thousands of times through a windowless gas target. Advances in laser technology and surface science now make it feasible to produce gases of polarized nuclei of sufficient thickness for internal target use (but not external beam use, where each electron goes through the target only once). Upon completion, the SHR will constitute a unique research facility, with many planned experiments and wide community interest.

   The Department of Energy has approved our pursuit of these research objectives as part of the base nuclear physics program. In FY89, a total of \$2.9M will be devoted to this development; this is about 25% of our budget. A concomitant reduction in the remainder of our research program will be required during the four-year SHR development period.

   The overall funding for the Bates Laboratory is far short of optimum and has led to significant underutilization over the last several years. Incremental "steady-state" funding of approximately \$2M per year would provide the resources needed for a robust research and educational program, i.e., five thousand research hours per year and the capability for developing the experimental apparatus needed for addressing the most significant questions in a timely way. With the major SHR experimental initiative, fiscal constraints will force a significant further reduction in the research program for FY89, FY90 and FY91. An increment of approximately \$3.5M over those years would permit both a vigorous research program and the development of the essential internal target and extracted beam capabilities of the SHR.

2. With the South Hall Ring experimental initiative at Bates and the major new facility at CEBAF, the American research community will have at its disposal unmatched capabilities for electronuclear research. These capabilities will be built upon novel technologies. The research programs at the two Laboratories will be complementary and synergistic. As noted above, the full polarization capability offered by the Bates SHR will be unique. The Bates extracted beam program will focus on high resolution studies of nuclear structure and collective motion. Our detectors are suited to this program. On the other hand, CEBAF will provide very intense, continuous beams in the energy regime up to 4 GeV, a regime where the focus will be on the quark description of nuclear forces and dynamics. The program centerpiece will be coincidence studies of few-body systems. The CEBAF detectors, now in the design stage, are being optimized for these efforts.

While the physics programs will be largely complementary in addressing many of the most pressing issues in nuclear physics, many of the developing experimental techniques will benefit directly from collaboration. For example, MIT and Illinois, with the participation of CEBAF, are now starting joint development of out-of-plane spectrometers for Bates. This will be a first and will be used immediately in our research program when available. However, out-of-plane spectrometry is also central to the future "second generation" CEBAF research program with high energy continuous beams. Indeed, certain information will be obtainable only in this way. Consequently, the Bates development will be viewed as an essential prototyping for the much larger instruments to be built later at CEBAF.

Finally, there is considerable intellectual exchange between the two Laboratories. Senior members from each Laboratory serve on the Program Advisory Committee of the other. As is clear from the example above, the research scientists at the Laboratories are in close contact. Many of our former students are playing key roles in building CEBAF.

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

Hearing on the Department of Energy (DOE)
FY 1989 Authorization Request for
General Science and Research

Republican Member Questions for the Record
for the Hearing of March 30, 1988, for
DR. ERNEST J. MONIZ, PROFESSOR OF PHYSICS AND DIRECTOR
WILLIAM H. BATES LINEAR ACCELERATOR CENTER
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

1. What will be the gap in FY 1989 between the level of operation that you can achieve with the proposed DOE allocation, and the optimal level of operation? How much funding would it take to close this gap?

2. How much additional research funding would be required to support an optimal level of operation?

3. Is MIT committed to strong nuclear physics program at Bates, and if so, how has MIT demonstrated this commitment?

4. How much longer do you believe that Bates can be productively utilized to conduct forefront nuclear physics research? Five years? Ten years?

Response

1.&2. The overall funding for the Bates Laboratory has not permitted full utilization of our unique capabilities. We have been operating at about 3000 research hours per year; full utilization would be about 5000 hours. An additional $2M per year, appropriately allocated between operations and equipment funding, would provide the resources needed for full utilization while developing the experimental apparatus needed for addressing the most significant questions in a timely way. Clearly, this would also have a major impact on our ability to train first-class graduate students.

During FY89, FY90, and FY91, we will be developing an especially important and novel experimental capability, that of internal target experiments with intense electron beams. This is the South Hall Ring (SHR) experimental development described in my testimony. This initiative will be pursued within the base program budget, therefore requiring a further reduction in the research program, to about 2000 hours per year, during that period. An increment of approximately $3.5M over those years would permit both a vigorous research and educational program and the development of the SHR capabilities.

3. MIT has a long and distinguished tradition in nuclear physics and remains strongly committed to the field. The Department of Physics currently has 21 academic staff (over 20% of the total) and 45 graduate students involved in nuclear physics research. Bates is the centerpiece of the MIT program. With the new experimental initiatives at Bates, the Department of Physics has extended an offer for a new Assistant Professorship (tenure-track) in our field. Further, substantial Institute resources were made available for planning the SHR initiative and approximately $2M of indirect cost recovery has been waived for the development period.

4. Bates clearly has a very productive future to the end of this century. Over the next several years, a number of unique programs will be continued. For example, we are the only facility in the world with the capability for performing nuclear structure studies through backward scattering (this is important for studying nuclear magnetization) and for producing intense polarized electron beams at intermediate energy. Further, we are developing, primarily in collaboration with the University of Illinois, a novel out-of-plane spectrometer capability. In the early part of the next decade, completion of the SHR will permit initiation of the internal target experiments. The polarized beam and out-of-plane capabilities will be essential for full exploitation of the internal target and extracted beam possibilities. The experiments already in the planning stage will demand several years of effort; indeed, the program pressure suggests that we must be careful to leave enough flexibility for acccommodating new ideas and new people. For the next century, any discussion about the research interests and technical developments would be pure speculation.

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
Subcommittee on Energy Research and Development

RESPONSE

Questions for the Record

Dr. Gerald T. Garvey, Director
Clinton P. Anderson Meson Physics Facility (LAMPF)
Los Alamos National Laboratory

March 30, 1988

Democrat Member Questions for the Record

1. *How would you characterize the role that the Los Alamos Meson Phyiscs Facility is playing during the period that the Continuous Electron Beam Accelerator Facility and the Relativistic Heavy Ion Collider are under construction?*

   As I mentioned in my testimony, our primary responsibility is to carry out world-class research. During the construction period of RHIC and CEBAF, LAMPF must carry, along with Bates and the heavy ion program at the AGS, a special responsibility for providing research opportunity in nuclear physics. This allows postdoctorals and graduate students to develop and demonstrate their ability to carry out further frontier research.

   Neither CEBAF nor RHIC replace LAMPF. They represent vital enhancements of our research capability with electrons and heavy ions. As these facilities near completion, it will be essential to increase LAMPF capability in hadron physics to retain the balance that has proven essential in nuclear physics.

2. *In your testimony you discussed the Advanced Hadron Facility that you proposed for Los Alamos. How are you able to develop the necessary plans and models for this advanced facility so that you would be ready by calendar year .993 to begin operations of this facility?*

   The planning and essential preconstruction R&D for an advanced hadron facility are severely limited by both administrative constraints placed on us by DOE and by the lack of an appropriate level of R&D funding. This situation must be rectified in the near future in order for cost-effective construction of the advanced hadron facility to begin in the mid nineties.

Republican Member Questions for the Record

1. *What will be the gap in FY 1989 between the level of operation that you can achieve with the proposed DOE allocation, and the optimal level of operation? How much funding would it take to close this gap?*

    The proposed DOE allocation for FY89 of $42,650.0 k for LAMPF operations allows 3,000 hours of beam time for research. We believe that 100% utilization of LAMPF capability would create 4,500 hours of beam time for research. The optimum level for FY89 would be 4,000 hours of beam time for research, or 33% more research time; hence, 4,000 hours represents an 89% utilization of full potential.

    A funding increase of $4,100.0 k (to a total of $46,750.0 k), or approximately 9.6%, is required to obtain the additional 1,000 hours for research!

2. *How much additional research funding would be required to support an optimal level of operation?*

    An additional $600.0 k in research funds would be required at Los Alamos National Laboratory to optimally use the 33% increase in beam time discussed in the response to question 1.

    A larger increase of about a factor of two ($1,200.0 k) would be needed for the external users of LAMPF.

3. *Do you believe that the management of Los Alamos National Laboratory is committed to maintaining a strong nuclear physics program at LAMPF, and if so, how has this commitment been demonstrated?*

    The Los Alamos National Laboratory Director, Dr. S. S. Hecker, has communicated on recent occasions his support of maintaining a strong nuclear physics program at LAMPF and the contributions made by the facility. In his March 3, 1988, statement to the House Armed Services Committee's Subcommittee on Procurement and Military Nuclear Systems FY 1989 Authorization Hearing, Dr. Hecker stated:

    > *Nondefense research and development at the weapons laboratories must first, of course, accomplish the specific purpose for which the funds were provided. In the basic research arena, the strengths of the weapons laboratories are in multidisciplinary basic research and research requiring the use of large facilities. The largest single basic research activity at Los Alamos is associated with the Clinton P. Anderson Meson Physics Facility (LAMPF), the world's most intense proton accelerator with energies in the 800-MeV range. This user facility brings to Los Alamos 300 to 400 experimenters per year, adding to the institutional prestige and introducing graduate students and postdoctoral fellows to the Laboratory. Key discoveries have emerged from LAMPF, including the first detailed measurement of the electron-electron neutrino scattering cross section, which has helped in the verification of the electroweak theory of fundamental interactions. Returning to the theme of multiple payoffs for a moment, LAMPF was initiated by weapons physicists for nuclear physics studies, then became used primarily by the nondefense basic research community, and has*

> *more recently yielded accelerator technology that has provided the basis for the NPB and FEL research programs for strategic defense.*

In another instance, Dr. Hecker wrote to Secretary Herrington on November 30, 1987, supporting LAMPF and it's proposed upgrade. Pertinent statements are quoted:

> *We at Los Alamos have as a very high priority the desire, and indeed have proposed, to upgrade our present Los Alamos Meson Physics Facility (LAMPF) to the status of a world-class facility of the kaon factory type referred to as an advanced hadron facility. . .*
>
> *The research activities related to LAMPF have had a large impact. The excellent nuclear physics research effort has added significantly to the country's knowledge base, contributed positively to the Laboratory's scientific reputation, and helped attract first-rate scientists to the Laboratory. Additionally, the present accelerator technology expertise at the Laboratory is directly related to LAMPF. Further, activities at the Los Alamos Neutron Scattering Center (LANSCE) depend on LAMPF beams as does the neutral particle beam program. . .*
>
> *The technical developments surrounding the construction of a new advanced hadron facility and the research program to be carried out there are certain to profoundly and positively affect this Laboratory's capability. . .*

And finally, from a communication to Senator Domenici dated March 19, 1987:

> *. . . In particular, it should be pointed out that during this period of construction [CEBAF and RHIC], LAMPF will be the mainstay of the nation's nuclear physics program. The science at LAMPF and the people it develops are crucial to the future of US nuclear physics and, hence, its funding support must be maintained. . .*

The Advanced Hadron Facility is the highest priority undertaking in basic research at Los Alamos. Thus, the Laboratory commits a part of its discretionary funds to help carry out the necessary research and development (R&D) to generate a technically sound proposal that contains reliable cost estimates.

4. *What, if any, technical issues remain to be resolved prior to the initiation of an Advanced Hadron Facility Upgrade to LAMPF?*

The Advanced Hadron Facility will use LAMPF as an injector. Acceleration to higher energy is done via rapid cycling synchrotron rings to yield high intensity. It is a straightforward extrapolation of existing technology. There are no fundamental problems that cannot be solved. However, to proceed in a cost-effective and timely fashion with the construction, a substantial investment is required in preconstruction research and development. The task includes, in addition to R&D, increasing the number of personnel at Los Alamos familiar with the technologies needed to construct such a facility. Among the R&D areas that must be addressed are:

- Beam dynamics
  - minimize beam loss in the injection systems,
  - design an efficient slow extraction system,
  - eliminate beam instabilities, and
  - design an internal collimation system to control any remaining beam loss.
- Rapid-cycling magnets and power supplies
  - develop a magnet and power supply that will achieve the specified field uniformity and cycling rate at reasonable cost.
- Ferrite-tuned rf
  - develop high power versions of the perpendicular-biased cavity for use in the booster and main ring of an advanced hadron facility.
- Injection, extraction, and beam-splitting hardware
  - develop high-intensity, rapid-cycling versions of equipment currently in use at high-energy accelerator facilities.
- Target cell equipment
  - develop remotely handled target systems, zero-degree production magnets, and beam transport equipment.
- Spallation neutron source
  - design a 1 MW cold-neutron source.
- Neutrino source
  - design a 1 MW version of the Large Čerenkov Detector, including beam handling, target cell, and shielding.
- Kaon beam technology
  - understand and eliminate the unwanted particles in kaon beams,
  - develop techniques for transporting kaons with minimum decay losses, and
  - develop dc and rf separators for use in a high-intensity, high duty-factor environment.

If this R&D is to be accomplished in a time-frame consistent with beginning construction in 1993 with workable solutions to all major problems, the present level of effort must be significantly increased.

5. *How much longer do you believe that LAMPF can be productively utilized to conduct forefront nuclear physics research in the absence of an upgrade? Five years? Ten years?*

This difficult question does not have a simple answer since forefront nuclear physics research is not uniquely defined. LAMPF has continued to increase its capability so that a broad spectrum of forefront research opportunities is available to the LAMPF user community. This process cannot continue indefinitely since the cost of upgrades generally increases as the facility matures. At some point it is far more cost-effective to rescope the facility with a major change, even though the cost is large.

If we consider the large spectrometers at LAMPF (HRS and EPICS), we find that many of the measurements first envisaged for these instruments are now complete. However, their utility continues due to their synergism with small-scale upgrades (<1 $M; for example: polarized nuclear targets, coincident particle detectors, etc.) and unexpected scientific opportunities such as the search for a dibaryon at EPICS. The remainder of the program at these facilities is essential to gaining a complete picture of the nucleus, but is not likely to produce a dramatic change in nuclear science. Such research is a necessary part of the science and provides a significant opportunity for smaller research groups and graduate student training.

In looking at mid-size upgrades of 1 - 10 $M, the MEGA experiment and the nearly completed Nucleon Physics Laboratory upgrades come to mind. The MEGA experiment is a forefront measurement in particle physics and should be completed within another four years. The Nucleon Physics Laboratory upgrade should be fully functional during 1989. One would expect the experimental program for this area to have reached maturity by the mid 90s.

The Large Čerenkov Detector (LCD) project is now under consideration by the DOE for funding in 1990. This is a world-class experiment to measure the fundamental constant of the electroweak unification. The funding of this project will place the LAMPF electroweak physics program in a forefront position for at least six years.

To assure forefront research at LAMPF beyond the mid-to-late 1990s probably requires a large-scale upgrade. A facility like an advanced hadron faciltiy would assure LAMPF of leadership in research through the first two decades of the 21st century.

Mr. **Chapman**. The Committee will be in recess until 1:00 p.m., and there will be a hearing at that time on magnetic fusion in this room, 2318.

[Whereupon, at 12:33 p.m., the Committee recessed, to reconvene at 1:00 p.m.]

APPENDIX

ADDITIONAL STATEMENT FOR THE RECORD

American Chemical Society

OFFICE OF THE
PRESIDENT
Gordon L. Nelson
President-Elect, 1987
President, 1988
Immediate Past President, 1989

1155 SIXTEENTH STREET, N.W.
WASHINGTON, D.C. 20036
Phone (202) 872-4600

March 31, 1988

The Honorable Marilyn Lloyd
Chairman
Subcommittee on Energy Research and Development
Committee on Science, Space, and Technology
U.S. House of Representatives
Washington, D.C. 20515

Dear Madam Chairman:

The American Chemical Society appreciates this opportunity to present its views on The Department of Energy's FY 1989 budget request and to offer some specific comments on support for research in the Office of Basic Energy Sciences (BES).

The United States is the recognized world leader in many energy and chemical technologies; but this leadership is being challenged. Long-term basic research activities supported by the BES program are essential to continue the Nation's leadership in these areas. The knowledge base for new technologies and future energy options springs from BES-supported research, thus helping to ensure that the U.S. maintains its energy and economic security and meets the challenge of increased international competition in science and technology.

Not only does the operating budget of BES fund long-term basic research, it also supports high-quality national research facilities heavily used by researchers in industry, government, and academe. These user facilities provide valuable opportunities for technology transfer and for the training of scientists and engineers. In fact, over 3,400 researchers from industry, government, and academe used these DOE research facilities last year.

The Society notes the proposed increases in FY 1989 for the operating expenses of the Chemical Sciences, Materials Sciences, Energy Biosciences, and Engineering and Geosciences programs within BES. However, a look at the historical budgets indicates that growth in these areas has been too low. This fact was highlighted in the conclusions of the Basic Energy Sciences Advisory Committee's December 1987 report, which stated that "....the funding of BES has not expanded enough to deal adequately with the needs, and certainly not the opportunities, facing the Nation and the DOE."

Budget Recommendations

One of the primary missions of the Department of Energy is to assure future access to abundant and clean sources of energy. Over 90 percent of the Nation's energy is based on chemistry. Given (1) the importance of chemically-related basic research to the DOE mission, (2) the need to have a secure energy-based economy, and (3) the trends in funding for the Basic Energy Sciences program, the American Chemical Society recommends:

- A 20 percent increase over FY 1988 be allocated to the operating budget of the Chemical Sciences Division, from $88.2 to $105.8 million.
- A 15 percent increase over FY 1988 be allocated to the operating budget of the Materials Sciences Division, from $126.0 to $144.9 million.
- A 15 percent increase over FY 1988 be allocated to the operating budget of the Energy Biosciences Division, from $20.3 to $23.3 million.
- A 20 percent increase over FY 1988 be allocated to the operating budget of the Engineering and Geosciences Division, from $31.4 to $37.7 million.

The Society recognizes the urgency of budget constraints. However, in the context of the promising research directions available, the budget growth being proposed is modest when compared to the potential benefits to the Nation's economic future.

Research Directions

Exciting areas of research now exist with definite promise for payoffs to the U.S. economy and the energy picture, and should be pursued. Oppor- tunities in the chemical sciences and engineering have been identified as key to America's energy future, in briefings and reports of the National Research Council; the Committee on Science, Engineering, and Public Policy (COSEPUP); and various government advisory groups.

The soon-to-be published National Research Council Report, "Frontiers in Chemical Engineering: Research Needs and Opportunities," identifies promising research thrusts in the areas of In-Situ Processing of Energy and Mineral Resources, Liquid Fuels for the Future, Advanced Computational Methods and Process Control, Surface and Interfacial Engineering, Microstructured Materials, and Biotechnology and Biomedicine. These areas have research and budget implications for the DOE Office of Basic Energy Sciences, particularly its Divisions of Chemical Sciences, Materials Sciences, and Engineering and Geosciences, as well as elsewhere in the Department.

Similarly, the 1985 National Research Council Report, Opportunities in Chemistry, showed that reaction dynamics, catalysis, combustion, corrosion, and plant sciences are essential to DOE's energy mission. The Department still has not responded adequately to the recommendations in this Report with new thrusts and new monies. These research areas relate directly to the chemical research supported in the Divisions of Chemical Sciences, Materials Sciences, and Energy Biosciences.

The Department of Commerce, in a recent review of emerging technologies and their impact on the economy (The Status of Emerging Technologies: An Economic/Technological Assessment to the Year 2000, June 1987), has concluded that, In order to remain competitive internationally, American industry by the turn of the century must master such key materials areas as superconductors, polymer composites, optical electronics, and advanced microelectronics. Materials science is at the heart of nearly all technologies that pace economic productivity, from industrial technologies to biomedical science to electronics to transportation to energy conversion. Chemists and chemical engineers must be given adequate budget support to play a key role if the U.S. is to meet this national agenda.

High-temperature superconducting materials--substances that lose all resistance to electricity below a certain critical temperature--could yield technological leaps in telecommunication, electronics, power generation and transmission, aerospace, and medical technology. The recent Report of the Research Briefing Panel on High-Temperature Superconductivity, COSEPUP, 1987, characterizes international competition in this field as intense, but indicates that the U.S. competitive position is good. The report concludes, however, that "Japan offers perhaps the strongest long-range competitive threat to the U.S. position." In view of this intense global competition, ACS believes that it is critical that research in high-temperature superconductivity be placed in an environment which will ensure long-term sustained funding. Here again, chemists and chemical engineers can play key roles in advancing an understanding of the properties of high-temperature superconducting materials, in the search for additional stable superconducting materials, and in devising chemical processes and methods for their wide application. An infusion of additional funding is urgently needed to continue the momentum of ongoing research. DOE's Basic Energy Sciences Advisory Committee has recommended that $30 million be added to the BES FY 1989 budget request for such research to be conducted in the Materials Sciences, Chemical Sciences, and Engineering and Geosciences programs.

Although the Society recognizes that there are high-temperature superconductivity initiatives in the budget request, it is not entirely clear from the budget documents that the research will be funded with new FY 1989 dollars. Therefore, it appears to us that the requested increases to BES programs are inadequate to pursue these and the other promising areas of research outlined above.

Benefits of Research

Research funded by the Chemical Sciences Division continues to contribute to fundamental knowledge about energy-related processes and developments--knowledge that has benefitted the Nation and has resulted in patents and commercialization.

An example of such success is the work of E. S. Yeung, Professor of Chemistry at Iowa State University and Senior Chemist in the Ames Laboratory, who has developed a new measurement technique. Dr. Yeung, 1987 recipient of the ACS's Award in Chemical Instrumentation, has combined the powerful laser with other scientific techniques to solve real life problems in energy generation, medicine, the pharmaceutical industry, and semiconductor fabrication. His patented micropolarimeter can record levels of optical activity much lower than those of previous measurements. He has applied this new methodology to determine optical activity in shale oil, coal, and coal extracts. The extent and nature of the optical activity, a measure of the right-handed or left-handed configuration of certain molecules, gives information about the age of the fossil materials and their geological origin.

Another application of this technique with far reaching consequences is its use in determining the level of blood cholesterol. High cholesterol has been correlated with atherosclerosis and heart disease. Current measurement techniques determine a single figure, while two forms of cholesterol, free and bound, are known to exist. The culprit in heart disease is thought to be the bound form. Yeung's new technique distinguishes between the two forms and measures each, as well as the total. The method is so sensitive that it improves on available commercial techniques by a factor of a thousand.

DOE-BES funded researchers also are attempting to make more of our energy resources economically usable. Natural gas, predominantly methane, is often found contaminated with nitrogen. It then has poor heating value and is less economically efficient to use. Chemical engineers at the University of Texas at Austin have prepared a new series of membranes which preferentially pass nitrogen rather than methane. This new process removes the undesired nitrogen, thus increasing the heating value of the remaining natural gas. The research looks promising and is being expanded to search for even more effective membrane materials.

Academic Research Support

The Society commends the Department of Energy for maintaining a strong component of its research at universities since they play a vital role in the research process. Currently, 34 percent of the BES research funds go to universities. The larger part of the total BES operating budget supports major facilities and research at national laboratories. Although the major facilities are heavily used by academic and industrial scientists and engineers, the balance among DOE research performers should be reviewed from time to time so as to determine the best mix to serve the Nation's interests.

The ACS believes that the University Instrumentation Program under the Office of Energy Research (OER) is underfunded. This subprogram was established to alleviate the pressing need among DOE researchers for state-of-the-art instrumentation costing over $100,000 each, and to allow graduate students to be trained with sophisticated research equipment. It also enables university researchers to employ "innovative" instrumentation on energy problems. This program was only able to support thirty awards in FY 1986. Strong proposal pressure coupled with flat funding over the past three years will allow this program to make only eighteen to twenty awards in FY 1989. In order to relieve this backlog of instrument needs in the academic community, the ACS recommends that Congress increase the University Instrumentation Program in FY 1989 by 50 percent to $7.5 million.

OER also reaches out through its University Research Support Program to provide research and educational opportunities at National Laboratories for university faculty, graduates and undergraduates, as well as high school science students and teachers. The Society supports the proposed increases for the semester-length research appointments at five science education centers located at DOE multiprogram laboratories. The ACS also supports the increases in the budget for educational opportunities for undergraduate science and engineering students, for elementary and secondary science students, and for high school teacher research programs. Our national well-being rests on a strong science and engineering work force. The ACS is pleased to see that DOE is playing a role in enhancing the quality and increasing the number of young people interested in pursuing energy related scientific and technical professional careers.

The ACS hopes these recommendations will assist your Committee in its deliberations on the DOE budget for FY 1989. The costs of the recommendations outlined are modest compared to the benefits to DOE's energy mission and to the economy as a whole.

Sincerely yours,

Gordon L Nelson

Gordon L. Nelson

cc: Members, House Subcommittee on
Energy Research and Water Development